# Anti Terrorism and Force Protection Applications in Facilities

This report is presented to the Department of Civil and Coastal Engineering graduate committee

Submitted by:
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# Abstract


Anti Terrorism and Force Protection Applications in Facilities

By

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June 2003

Major Department: Civil and Coastal Engineering



Terrorist attacks were once predominately focused on US military posts or US embassies overseas, and the perception has been the danger was “over there”. However there have been recent foreign and domestic terrorist attacks have occurring in the US. The most common form of the attack is a moving or stationary vehicle to carrying home-made explosives and detonating it at Federal, commercial, industrial, or educational facilities which are perceived symbols of the US. This report will review the general properties of a bomb blast, defense plan development, the concept of defense in depth for an urban planning layout, and preventing progressive collapse of a structure. A review of lessons learned from the case study of the 1993 World Trade Center, Oklahoma City, Beirut, and Khobar Towers. The last area will be final conclusions and recommendations when considering defensive applications.

> *We are not in the business of protecting buildings; we are in the business of protecting people.* Final Report from the Building Systems Security Summit, March 8, 2002.

## 1.0 Introduction

Blast resistant or bomb proofing of buildings are more apparent in munitions storage depots, fuel depots, or strategic missile defense posts. Within the past 20 years US occupied buildings, commercial use, and residential compounds have been attacked by terrorist organizations. Some of the major attacks were:

1983 – US Embassy and US Marine Corps barracks in Beirut, Lebanon
1993 – World Trade Center
1995 – Murrah Federal Building in Oklahoma City
1996 – Khobar Towers in Saudi Arabia
1998 – US Embassies in Kenya and Tanzania
2001 – World Trade Center and Pentagon Building

With each attack the trend of developing blast resistant buildings has applied specifically for overseas US embassies and key domestic national assets. It was not until the 1993 attack on the World Trade Center that showed the US was susceptible to foreign terrorist attacks. Punctuating US vulnerability was the domestic terrorist attack on the Murrah Federal Building in Oklahoma City. Any symbol of the US can now be viewed as a potential target. Blast mitigation knowledge has not successfully transferred towards civilian/commercial development; as such information has been restricted for Federal use only. After the Oklahoma City bombing, the specialty of designing blast resistant buildings has grown, and so has the amount of unrestricted sources of information, though it may never be balanced with the amount of information available for use on military bases and US embassies.

A common thread of the attacks has been the use of a vehicle or car bomb. Of course the last major attack on the World Trade Center and Pentagon Building used commercial aircrafts as their weapon; however the likelihood of a car bomb being used again is high, as the delivery of home-made explosives in an automobile or truck can be simple to reproduce. This report will be limited to such an attack and will not investigate attacks by nuclear, biological or chemical means; as such methods are lengthy subjects by themselves. This report will review blast mitigation in the defensive application of facilities, based on available unclassified information. This report will review the general properties of a bomb blast, defense plan development, the concept of defense in depth for an urban planning layout, and preventing progressive collapse of the structure. Since hind sight is 20/20, a review of lessons learned from the case study of the 1993 World Trade Center, Oklahoma City, Beirut, and Khobar Towers, will help illustrate defensive requirements. The last area will be final conclusions and recommendations when considering defensive applications.

## 2.0 Explosion Basic Principles

As an explosive detonates, a chemical reaction converts the material into energy in the form of the rapid release of high pressure gas, heat, light, sound, and a shock wave. The shock wave expands outward from the explosion in all directions, traveling at supersonic speed and exerts pressure on any structure in its path. The pressure wave decays as the distance from the explosion and time increases. There are two aspects of the shock wave that inflict damage, one is the peak amplitude of the pressure and the other is the duration of the pressure applied on the structure. Figure 1 is a display of the pressure over time of the blast wave. The Impulse is the area under the curve in Figure 1 and is equal to the amount of momentum applied to a structure.

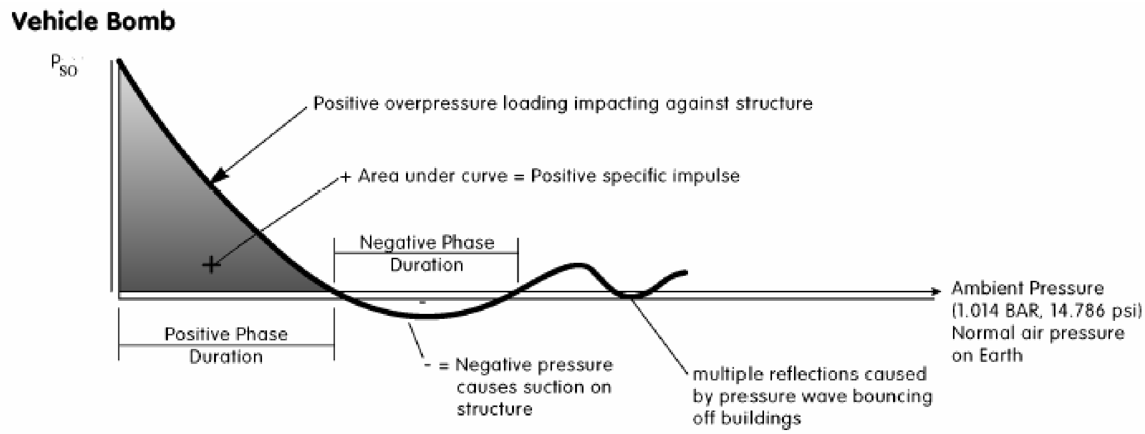



**Figure 1 – Pressure versus Time Graph of a Shock Wave. [1]**

Note in Figure 1 that there is a negative pressure phase that causes suction in the path behind the shock wave. This causes an air blast to fill in behind the wave and the air blast is capable of carrying debris along with it. As the shock wave propagates and impacts on a structure, the wave will reflect from the structure. The reflected pressure is at least twice that of the incident shock wave and is proportional to the strength of the incident shock, which is also proportional to the weight (yield) of the explosive. [2]

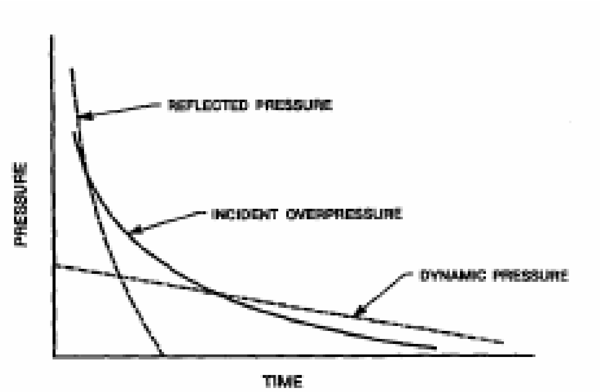



**Figure 2- Comparison of Reflected and Incident Pressure on a Structure. [2]**

Figure 2 shows the relationship of the incident and reflected pressure on a structure.

If the explosion occurs at or slightly above ground level, part of the blast energy will be used in creating a crater and propagating the shockwave underground. The underground shockwave will act as a localized earthquake. However the shockwave will act in compression instead of shear as a normal earthquake. Fragments of the bomb and vehicle will break up into large pieces, and expelled in all directions around the blast. In general, these fragments are not significant in creating damage to a structure, as compared to the shock wave. However airborne debris such as broken glass, broken concrete, wooden splinters (damaged parts of the building), created by the explosion, is capable of injuring building occupants. The fire created by the explosion itself is also not significant to structure damage as compared to the shock wave. However secondary fires due to damaged electrical systems are capable of injuring building occupants as well as delaying occupant rescue.

### 2.1 Equivalent Explosive Weight

The charge weight of the explosive is typically measured in the net equivalent weight of TNT, as TNT is the US standard explosive in assessing blast effects. The most common home-made type of explosive is fertilizer-fuel mixture or Ammonia Nitrate Fuel Oil (ANFO). ANFO's average equivalent weight factor to TNT is 0.82, or 82% the blasting power by equivalent weight in TNT. [3] Typical defensive planning is for a vehicle to carry anywhere from 50 pounds – 4,000 pounds of explosive. However the largest size used is in the attack on the US Marine Barracks in Beirut, Lebanon, which was calculated to be 12,000 pounds. For reference the explosive weight of the standard US hand grenade has 0.85 pounds, US 81mm mortars range from 1.29 pounds – 4.30 pounds, and the average sized ordnance deployed by aircraft during Desert Shield/Desert Storm was 1,000 pounds "bunker busters". [3]

### 2.2 Blast Scaling

For damage assessment, blast from any type of explosive (using equivalent weight of TNT) can be scaled with varying distances from the explosion and varying explosive weights. The peak pressure is a function of distance R from the explosion divided by the cube root of the charge weight W. This is commonly called scaled distance and expressed as: **Scaled Distance = $R / W^{1/3}$**

Another way of viewing scaled distance and pressure relationship is by:

$$\textbf{Peak Pressure} \sim W/R^3$$

In this relationship, peak pressure is reduced by a factor of 8, if the range is doubled. Figure 3 plots out the above relationship with four incident pressure curves (0.5, 1.0, 2.0, 10.0 psi) that would apply on varying explosive weights (log scale) and stand off distances. The vehicle symbols/colors at the top of Figure 3 display the relative size of the vehicles that might be used to transport differing amounts of explosives.

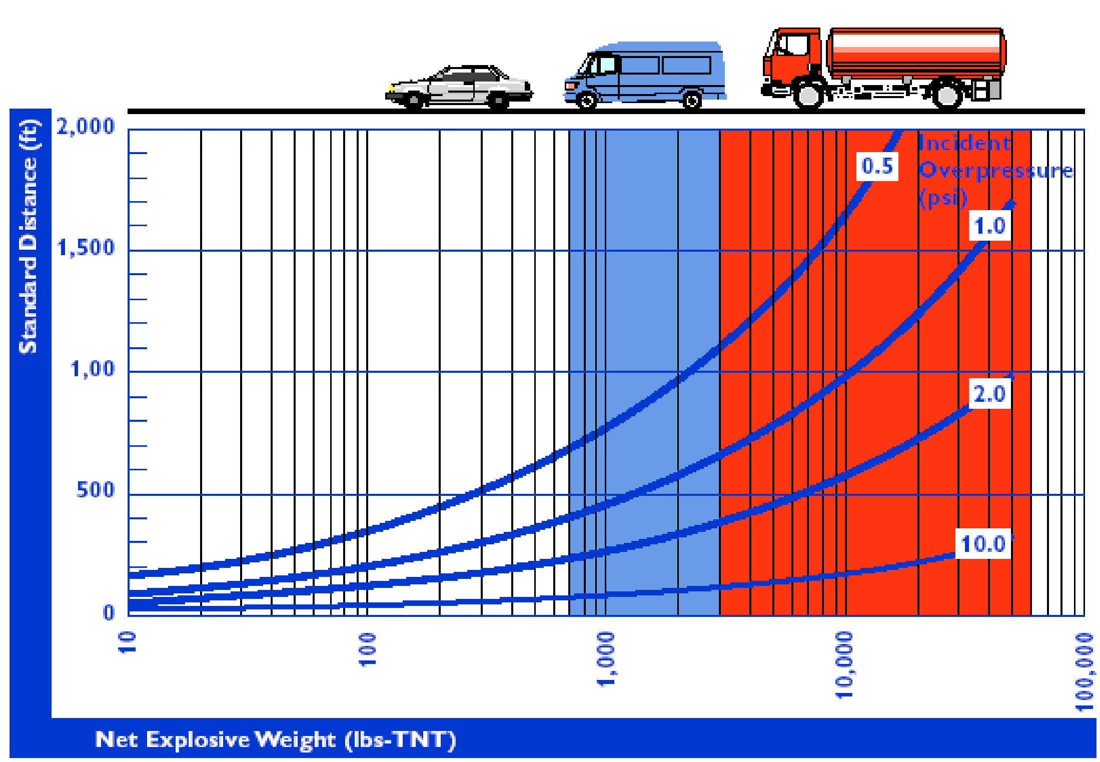



**Figure 3 – Incident Pressure Related to Stand Off Distance and Explosive Weight. [4]**

### 2.3 Blast Effects on Structures

As the shock wave propagates through a building, the pressure engulfs the entire structure first with the walls incident to the blast, then the roof and side walls, and then opposing rear wall last. At a single point in time the entire surface of the structure will be under a blanket of pressure from the shock wave. Damages to various building types based on computer simulation are from *User's Guide on Protection Against Terrorist Vehicle Bombs* (UG-2031-SHR) are listed in Appendix A. [1] The size of the structure relative to the bomb size is a significant factor in the amount of damage produced, as well as the type of construction and the size of the weapon. Structures that are rigid sustain more damage than structures that are able to flex and adjust to the blast, similar to building movement during an earthquake or hurricane/typhoon. Summary of the assessment is as follows:

a. Damage is prevalent for wood construction even at large stand off distances. This is due to the inherent fragility of wood components to explosions.

b. Reinforced concrete frames offer a high level of blast resistance.

c. Reinforced concrete performs better than concrete masonry unit (CMU).

d. The height of the structure is a factor in its ability to survive. A small, strong CMU building may withstand damage better than a large, two-story, lightly reinforced concrete building.

### 2.4 Blast Effects on the Human Body

When the blast wave propagates through a resilient object such as the human body, the body's tissues undergo rapid compression and decompression. This is due to the reflection and refraction of the stress wave at the interface of differing densities. Areas of different densities are at the bone and muscle, or between tissue and air void space. The lungs and the gastrointestinal system are areas of tissue and air void interface. The resultant tissue damage can lead to internal hemorrhaging or the development of air embolism, either of which can be fatal. Additionally eardrum rupture or damage leading to full or partial/temporary hearing loss is a common blast injury. Table 1 summarizes a typical range of probability of lethality with variation in overpressure, and Table 2 lists the injuries sustained for varied stand off distances and explosive weight.

| **Pressure (psi)** | **Approximate Lethality Percentage** |
|---|---|
| 23-33 | 1 |
| 33-58 | 50 |
| 58+ | 99 |

**Table 1 – Probability of Lethality on Varying Pressure. [1]**

| **Personal Injury Level Expected** | **50 lbs** | **220 lbs** | **500 lbs** | **1,000 lbs** | **4,000 lbs** |
|---|---|---|---|---|---|
| Severe injury or death | 33 | 54 | 71 | 90 | 142 |
| Lung injuries and 20% eardrum rupture | 40 | 66 | 87 | 110 | 174 |
| Serious injuries (Internal bleeding, some organ damage) | 66 | 108 | 143 | 180 | 285 |
| Injury (Lacerations and contusions, no organ damage) and temporary hearing loss | 95 | 151 | 198 | 250 | 396 |
| Injury from debris (Lacerations and contusions) | 110 | 181 | 238 | 300 | 475 |

**Table 2 – Distances to Produce Personal Injury (feet). [1]**

## 3.0 Force Protection Process

Force protection is a security program designed to protect people, facilities and assets. To ensure proper the proper level of protection is designed for varying levels of threats, the four phases in developing a force protection plan must be analyzed: Threat Analysis, Vulnerability Analysis, Identification of Security Strategy, and Implementation. Threat Analysis is the collection and assessment of terrorist and criminal information, capability, and potential. Vulnerability Analysis is the assessment of critical assets and their vulnerability to terrorist or criminal attacks. Identification of Security Strategy forecasts the protection procedures, actions, and measures to respond to threats, balanced with any limitations to the owner or his facilities (funding, limited ground space, zoning limits, historical site preservation, traffic flow, etc.). Implementation is the action of installing or engaging the finalized force protection plan.

The steps described in developing a force protection program are from the Department of Defense (DoD) Anti Terrorism Standards (DoD Instruction 2000.16), DoD Minimum Anti Terrorism Standards for Buildings (UFC-4-010-01), and U.S. Air Force Installation Force Protection Guide. To make the process universally applicable, the force protection assessment may be use crime prevention methodologies.

### 3.1 Threat Analysis

Identification and assessment of terrorist and criminal threats are the first steps in creating a force protection plan. Once owners understand the threat, they can assess their facilities' ability to survive an attack. The threat analysis defines the parameters on which protective systems and actions are based. The steps for threat analysis are shown below in Figure 4. The collection of information in each of these steps can be found in from several organizations such as, DoD, Department of Homeland Security, Federal Bureau of Investigations, as well as newspapers, local police and state government agencies.  Crime statistics and local criminal activity is a useful tool in assessing threats as attacks can be from domestic as well as foreign terrorists.

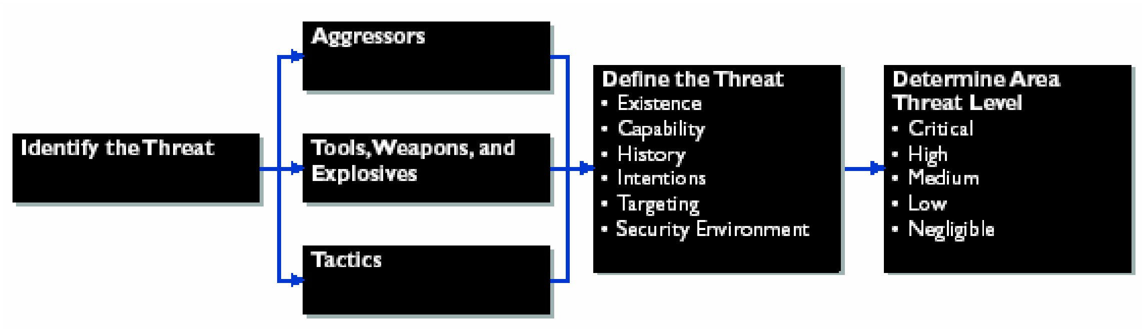



**Figure 4 – Threat Analysis Steps.  [4]**

Identifying the threat involves three components:  Aggressor; Tools, Weapons, and Explosives; and Tactics.  Aggressors are groups or individuals who commit the hostile actions against people, facilities, or equipment.  Their objectives can include:

a. Cause injury or death
b. Destroy facilities, property, equipment, resources, or information
c. Theft of funds, equipment, material, resources, information, or anything of value
d. Stop or delay commercial or industrial production such as timber logging, Defense contractor, etc.
e. Create or enhance publicity for their cause

The tools, weapons, and explosives of the aggressor can vary from simple surveillance equipment, to small arms, to chemical agents, to home made or military issue explosives. The tools and weapons of choice by the aggressor will be those that are most readily available or available by black market sources.  Common sources can be used for readily available items for use in surveillance or tools for forced entry to gain initial information on their target.  The tactics of the aggressor is his offensive strategy in employing his weapons to achieve their objectives. From the point of view of this report, the strategy and weapon will be either a moving or stationary vehicle bomb placed near the target facility. The following is a list of other tactics that could also be employed to gain entry into a facility or to cause destruction:

a. Exterior Attack – rocks, hand grenades, or small weight explosives
b. Stand Off Weapons Attack – military weapons such as anti tank missiles or mortars
c. Sniper Attack – use of small arms to inflict casualties or halt production
d. Covert Entry – enters the facility with false credentials
e. Mail Bombs – incendiary or chemical bombs used in envelopes or packages
f. Airborne or Waterborne contamination – chemical or biological agents [4] [11]

Gathering intelligence on the aggressors can be difficult as such organizations work in secrecy. Similar to urban city police work on combating gang violence, understanding gang subculture is the first step in defining the threat. The DoD has developed six factors or questions used in assembling information on a possible threats. Threat definitions listed Figure 4, are further explained.

a. Existence – who is hostile against the owner's organization, associations, or social groups?

b. Capability – what weapons/tools/explosives has the aggressor used in the past and what is their capability to train, supply and carry out attacks?

c. History – what have the aggressor done in the past, and what has been their method of operation?

d. Intentions – why do the aggressors engage in such attacks, and what did they hope to achieve?

e. Targeting – who is a likely target, why, and possibly when?

f. Security Environment – what are the owner's internal security capabilities to deal with an attack as well as expected external support to defend the attack (local police, FBI, local Fire Department, crime watch groups, etc.)?

Using the above six factors in assembling information on potential threats; DoD has developed a hierarchy of Threat Levels for an area, or region. Figure 5 outlines the threat level based on being able to answer (affirmative or negative) the above six threat definition factors. The greater amount of affirmative information generated by the threat definition factors, the higher the threat level. The only factor not applied in the threat level determination is the Security Environment, as this factor is adjusted as the threat level increases or decreases. Similar matrix can custom tailored by any other organization wanting to develop protective posture levels for their force protection plan. In most cases, the number of threat levels can be reduced for simplification from DoD's five threat levels to three by only using High, Medium, and Low. Critical and Negligible levels are hardly used and can be masked with the High or Low levels.

| THREAT LEVEL | THREAT ANALYSIS FACTORS | | | | |
|---|---|---|---|---|---|
| | Existence | Capability | History | Intentions | Targeting |
| Critical | ■ | ■ | □ | □ | □ |
| High | ■ | ■ | ■ | ■ | |
| Medium | ■ | ■ | ■ | □ | |
| Low | ■ | ■ | □ | | |
| Negligible | □ | □ | | | |

■ Factor must be present □ Factor may or may not be present

**Figure 5 – DoD Terrorist Threat Levels. [4]**

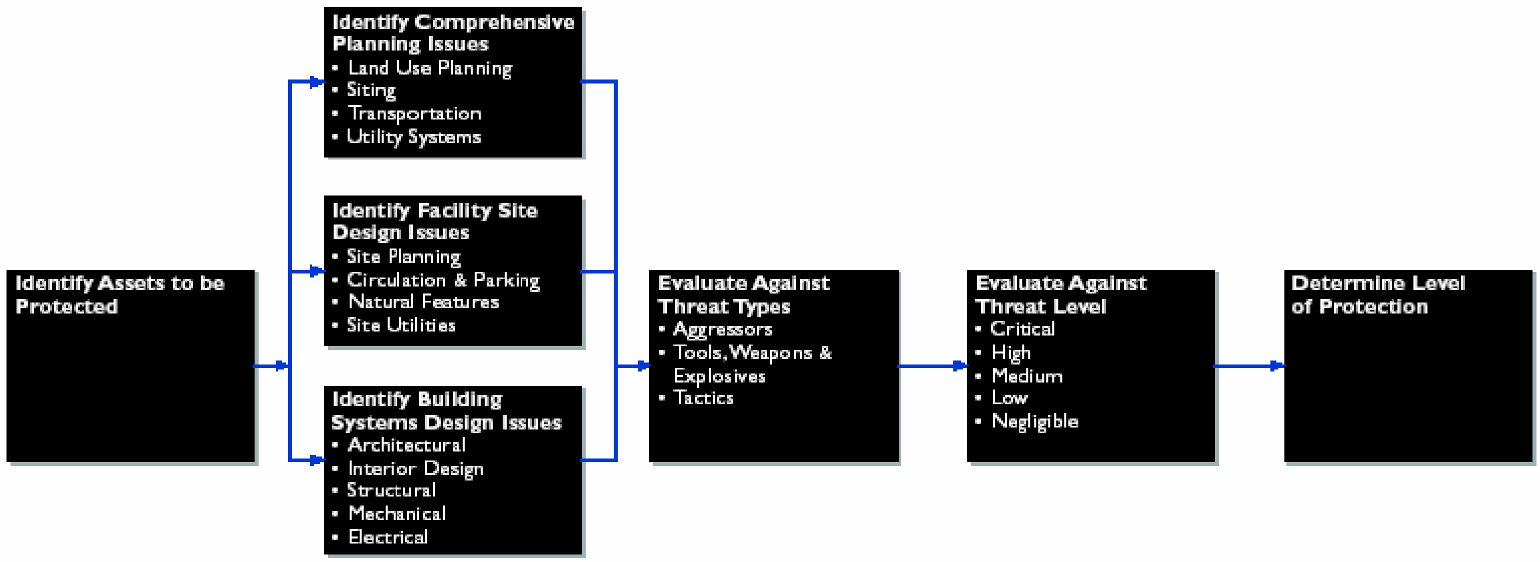



**Figure 6 – Vulnerability Assessment Steps. [4]**

### 3.2 Vulnerability Analysis

The vulnerability analysis identifies how the owner's facilities are susceptible to attack and provides the basis for designing the defense against such attacks. Figure 6 identifies the steps in the process. The analysis is typically accomplished by contracted experts comprised of engineers, urban planners, and retired military who will be able to review the facilities and compound and assess how similar aggressors would focus the attack, based on perceived weakness. The first step in the analysis is to determine which structures need to be defended. Typically this will be the owner's cognizant, and generally will be the critical operational facilities as well as buildings or areas that have concentrations of personnel or resources. The next step is to review land use planning, traffic flow, natural terrain, and building system designs that could be used in defending against an attack. The final step is then to compare the assessment against the earlier identified threats and varying threat levels to determine the required level of protection.

### 3.3 Identification of Security Strategy

This phase of the process is balancing the existing security options against the owner's known constraints. Typical types of constraints are physical, resources, and political. The physical constraints can be congestion of the buildings, relative closeness to public right-of-ways, emergency vehicle access, or limits on expansion of property boundaries. Resource constraint is typically limited funds to implement the defensive strategy. Political constraints can be historical preservation, zoning restrictions, civic groups, as well as limiting the appearance of the defensive designs so that the facilities does not appear as a fortress or war zone.

### 3.4 Implementation

The final phase is implementing the force protection plan's designs and approved strategies. If the owner has unlimited resources, then this could be a simple of process of contracting the installation of the defenses. However the likeliest case is the owner has limited resources and the challenge of implementing the design is more the norm than the exception. For DoD the implementation can involve several funding sources to complete the final project, such as Congressional Military Construction Funds (MILCON), local Operation and Maintenance Funds (O&M) or from other sources such as groups that are incorporating similar protective plans into their own systems (Electrical Power, Water, and Waste Water Utilities). An owner can leverage local government funding by showing how critical the asset is to a community, such as a hospital or communications center, and develop collective protection groups to cumulate funding resources.

## 4.0 Defense in Depth

Defense in depth is to provide several layers that aggressors much breach before reaching the protected facility. The concept is similar to peeling away successive layers of an onion to reach the center. The use of distance as a defensive tool may be the most cost effective option, as shock wave pressure decreases by a factor of 8, each time the stand off distance is doubled. To create a protected space for the critical facilities, barriers will need to be erected to form a perimeter. The barrier can be man made, use of the natural terrain, or reconfigured with changing threat levels. Entry into the protected area will be through controlled entry points. The main focus will be to limit the vehicular traffic in and out of the protected area. In certain situations pedestrian traffic may or may not be limited. This may all sound similar to creating a fortress however the appropriate use of natural barriers and allowance of free pedestrian traffic can overcome this perception.

Orientation and layout of the facilities is also key in defense in depth. Two defensive issues to be addressed:

a. Denying the aggressor a straight or direct route to the critical facility.

b. Denying the aggressor a clear line of site to the critical facility.

The defense to the first issue is to build routes that require vehicles to reduce their speed or prevent acceleration and therefore preventing use of their vehicle as ram. This can be accomplished with multiple turns or points where vehicles must stop. This subject will be further reviewed under 4.3 Controlled Entry Points. The defense to the second issue is to place the critical structures away from direct view of surveillance or stand off weapon attacks such as anti-tank missiles or rocket propelled grenades. This can be accomplished by using the natural terrain of hills as cover, or to install visual obstructions such as trees or shrubs. Visual screens may be another option however they have the disadvantage of sustaining wind damage or act as foreign object damage (FOD) during a storm, and therefore would need to be replaced multiple times during the storm season.

### 4.1 Stand Off Distance

The stand off distance is defined by the type of threat and the threat level, Figure 3. In most cases the cost of force protection increases as the stand off distance increases. This is the trade off of hardening a structure to withstand higher blast pressure. The area within the stand off distance can be further partitioned, Figure 7. The exclusive stand off zone rates a higher level of protection. Using the concept that vehicles are able to carry significantly more explosives than a person with a hand carry packages, the exclusive zone would be limited to pedestrian traffic only. Service or emergency vehicles would be allowed access on a case by case basis, and would be monitored when inside the exclusive zone. The non-exclusive stand off zone would permit entry and parking of automobiles and trucks, after initial search at an earlier entry control point.

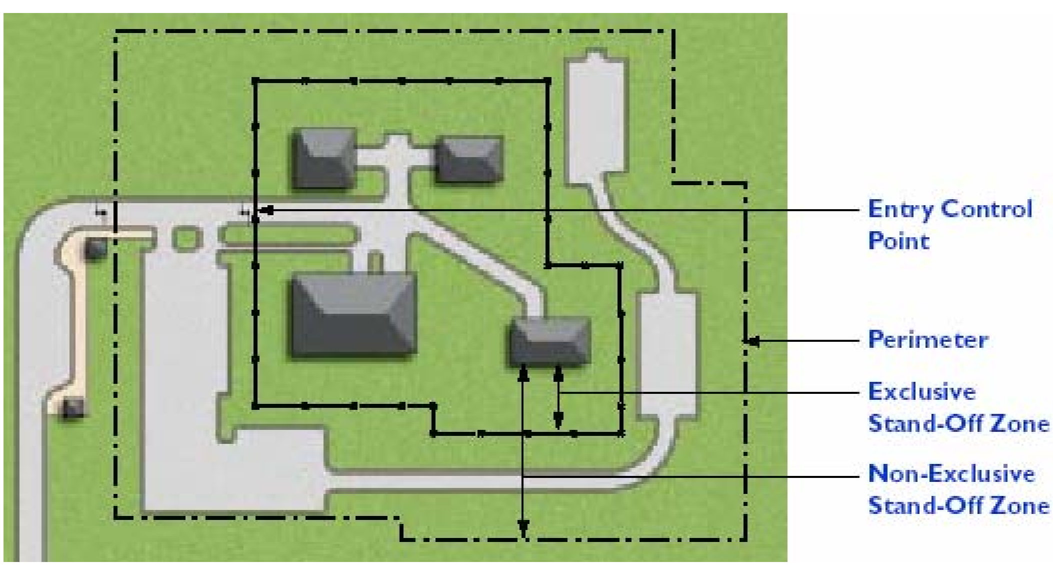



**Figure 7 – Exclusive and Non-exclusive Stand Off Zones. [4]**

The DoD minimum standard for effective stand off distance for billeting and primary gathering buildings is 25 meters (82 feet) away from parking and roadways without a controlled perimeter, but is reduced to 10 meters (33 feet) for the same facilities inside a controlled perimeter. [11] This is based on the assumption of a stationary vehicle bomb attack and the facilities are constructed of reinforced concrete or reinforced masonry. If the buildings are of light-weight construction such as a metal paneled pre-engineered building, then the standoff distances would need to be greater. The DoD has also classified the stand off distance for trash containers to be 10 meters (33 feet) for inside and outside of a controlled perimeter. [11]

### 4.2 Barriers and Barricades

The most common barriers in use today are the chain linked fence and concrete jersey barriers for use as temporary barricade. The chain linked fence is an effective barrier when reinforced with high strength cables to prevent penetration by ramming vehicles, and monitoring by closed circuit (CC) TV's or with security personnel. Both have the advantage of being installed very quickly. However both lend towards the appearance of a fortress. Another option is to actually build concrete or masonry unit walls. If constructed with reinforcing, then the wall would be superior to the chain linked fence. Additionally the aesthetics wall textures and paint can make it more attractive. However the wall does add to the fortress appearance.

**Figure 8 – Comparison Between Commercial Chain Linked Fence and Concrete or Masonry Unit Perimeter Wall. [5] [6]**

Another method of barriers from vehicle bombs is to use the existing terrain. This could be an area of heavy woods, stream bed or lake. Use of earthen berms or ditches can be used as part of the barrier system. Though the likelihood of having a stream bed or lake near any industrial area is very small, a retention pond in conjunction with earthen berms can be created. This had the added benefit of creating storm water discharge area for parking lots and similar paved areas. If the pond is large enough, walking or running paths could be created on its perimeter. The additional pedestrian flow would be the added "set of eyes" to notice any unusual activity.

**Figure 9 – A Retention Pond at a Housing Complex as a Barrier.**

Another method of creating vehicle barriers is from the National Capital Planning Commission (NCPC). The NCPC has been charted with providing security planning to our nation's capital. With the political and historic aspects to the area, standard chain linked fences and concrete jersey berms will only work as a short term solution. The NCPC had constraints of maintaining vehicular traffic flow past the Federal buildings as well as the national monuments. The solution is to improve the "streetscape" by increasing the pedestrian paths in front and around these structures by removing the existing street parking and installing in its place permanent barriers such as curbs, bollards, planters, decorative fencing, trees, and dense shrubs. Figure 10 A is a view of the ring of temporary jersey barriers around the Washington Monument. It is clearly visible from this photo that the concrete jersey barriers are not appropriate for a national monument and does not project a first class appearance of a world power. Figures 10 B and C are examples of the proposed improvements to the streetscape. Note the aesthetic appeal of the use of bollards, permanent benches, trees, and planters as barriers to

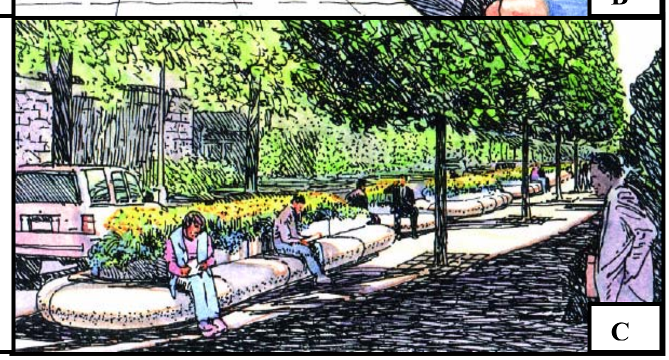




**Figure 10**
**A: Jersey Barriers Around the Washington Memorial.**

**B: Proposed Upgrade to E Street, SW**

**C: Proposed Upgrade to D Street, SW**

vehicles, while enhancing pedestrian traffic. The location of the bollards, benches and planters is the site of the existing street parking, therefore the stand off distance to the Federal buildings has increased by approximately 15 feet. Not visible in Figures 10 B and C is the continuous six inch curb facing the street as part of the barrier system.

### 4.3 Controlled Entry Points

The controlled entry points allow the movement of vehicles and personnel in and out of secure exclusive and non-exclusive zones. The first step in designing the control points is determining its location. This step is accomplished by understanding what facility is the critical structure, then determining the minimum stand off distance required to protect the structure from the expected size of explosive detailed in the force protection plan. In most cases, the location of the control point will be predetermined, due to existing street or routes leading to the owner's facilities. The second step in the design concept is to develop the route leading to the facilities with barriers so that security personnel can prevent or crash unauthorized vehicles before entering the secure area. This is accomplished by creating stops and turns in the route with passive and active barriers. Passive barriers are permanent fixtures such as curbs, bollards, fences, and walls. Active barriers are moveable gates controlled manually or electronically by the security personnel. See Appendix B for examples of active barriers and a table of Department of State approved barriers. Other design parameters to be considered are:

a. Peak Traffic Flow
b. Space Available
c. Owner's Mission
d. Construction and Operational Budget
e. Environmental Factors
f. Interface with local government
g. Traffic Safety
h. Interaction with surrounding roadway and intersections [8]

Of the eight factors listed above, the two that most likely will be the controlling factors are Space Available and limited Budget. Another factor to be considered is that emergency vehicles such as fire trucks and ambulances must be able to navigate their way through the controlled entry point, though the peak traffic flow is based moving the smaller sized passenger vehicles.

Vehicle speed at the time of impact to the barrier will determine the performance requirements for the barrier. Use of the dynamics equations of bodies in motion will assist in the design:

$$\mathbf{v = v_o + at}$$
$$\mathbf{x = v_o t + (at^2)/2}$$
$$\mathbf{v^2 = v_o^2 + 2ax}$$

v is velocity, a is acceleration, t is time and x is distance. $v_o$ is the velocity at time t = 0. Factors affecting the acceleration speed will be the vehicle's initial speed, the acceleration, and the distanced allowed for the vehicle to accelerate. For a straight path Table 3 shows the impact speed attained for varying distances. The acceleration of a passenger vehicle (4,000 pounds) is 10 feet/second$^2$ and for a delivery truck (15,000 pounds) is 6 feet/second$^2$.

| | Distance to Barrier (feet) | | | | | | |
|---|---|---|---|---|---|---|---|
| Acceleration Rate (ft/sec$^2$)↓ | 200 | 400 | 600 | 800 | 1000 | 1200 | 1400 |
| 6 | 33 | 47 | 57 | 66 | 75 | 82 | 89 |
| 10 | 43 | 61 | 74 | 86 | 96 | 106 | 114 |

**Table 3 - Speed of Vehicle From a Dead Start (miles per hour). [1]**

The slope of the route can increase or decrease the vehicle speed. Table 4 lists the correction factors to the vehicle speed based on varying positive and negative slopes.

| | SLOPE ← DOWNHILL | | | | | UPHILL → | | | |
|---|---|---|---|---|---|---|---|---|---|
| Acceleration Rate ($ft/sec^2$)↓ | -25 | -20 | -15 | -10 | -5 | 0 | 5 | 10 | 15 |
| 6 | 0.30 | 0.35 | 0.41 | 0.52 | 0.68 | 0 | 1.88 | 14.3 | - |
| 10 | 0.42 | 0.48 | 0.54 | 0.64 | 0.78 | 0 | 1.38 | 2.27 | 5.55 |

**Table 4 - Speed Correction Factors for Vehicles Driving on Negative (-) and Positive (+) Slopes. [1]**

Curves in a route will also force the driver to reduce vehicle speed, otherwise will lead to skidding and eventually toppling vehicles with high centers of gravity. If the vehicle topples, then it is essentially prevented from continuing the attack. However if only skidding occurs, the aggressor may continue his attack. Table 5 lists the skidding speed based on various sizes or curves. The friction coefficient of 0.6 is for dry paved road. If the existing road surface is unknown, then using 1.0 friction coefficient is a conservative approach. The "tighter" the curve the slower the vehicle will travel.

| | Radius of Curvature (ft) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Friction Coefficient (μ) ↓ | 25 | 50 | 75 | 100 | 125 | 150 | 175 | 200 | 225 | 250 |
| 0.6 | 15 | 21 | 26 | 30 | 33 | 37 | 39 | 42 | 45 | 47 |
| 1.0 | 19 | 27 | 33 | 39 | 43 | 47 | 51 | 55 | 58 | 61 |

**Table 5 - Skid Speed (mph) vs. Radius of Curvature (ft). [1]**

It is clear from Tables 3 to 5 that reducing the distance to accelerate as well as routing vehicles through curves that the impact speed can be significantly reduced. This then reduces the performance requirement of the barriers, and therefore reduces the cost of construction. If the design constraint is limited by use of an existing straight route to the controlled entry point, use of barriers can still force the driver to take a serpentine route, and therefore reduce vehicle speed, Figure 11.

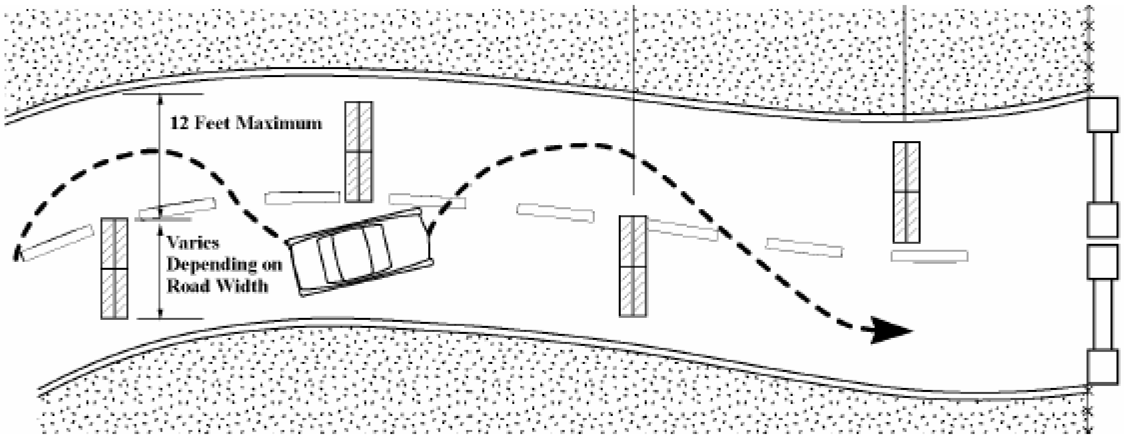



**Figure 11 – Barriers Use to Create a Serpentine Route. [1]**

For a vehicle to penetrate the control entry point or barrier, it must achieve a higher level of kinetic energy than what the barriers have been designed. The applicable equation is **KE (ft-lbf) = 0.0334WV$^2$**, where W is the vehicle weight and V is the vehicle's impact velocity. Table 6 outlines the varying kinetic energy generated by a passenger vehicle and delivery truck at varying impact velocities. For reference, the kinetic energy absorbed by an anchored jersey barrier is 334.4 x 1,000 ft-lbf; standard chain linked fence is 61.9 x 1,000 ft-lbf but supplemented with a cable is 346.8 x 1,000 ft-lbf; and a bollard system (8 inches diameter pipe, placed 3 feet on center) is 1,108 x 1,000 ft-lbf.

| | Speed of Vehicle | | | | | | |
|---|---|---|---|---|---|---|---|
| Vehicle Weight ↓ | 10 | 20 | 30 | 40 | 50 | 60 | 70 |
| 4,000-lb Vehicle | 13 | 53 | 120 | 214 | 334 | 481 | 655 |
| 15,000-lb Vehicle | 50 | 200 | 451 | 802 | 1253 | 1804 | 2455 |

**Table 6 – Kinetic Energy Developed by Vehicle Weight and Speed (1,000 ft-lbf)**

Besides the barriers, typical components of a controlled entry point may include the following:

a. Guard House

b. Passenger Vehicle Access
c. Truck or Delivery Vehicle Access
d. Pedestrian Access
e. Lighting
f. Communications and Monitoring System
g. Inspection Area
h. Signage
i. Rejected Inspection Departure Route [8]

The Guard House supports security personnel as a defensive posture against attack and as a work station. The guard house will need to store weapons, inspection equipment, communications equipment (radios and telephones) and monitoring equipment such as closed circuit TVs. Bullet proofing of the guard house will ensure security personnel will survive an attack.

The controlled entry point will need to support 3 separate methods of entry: pedestrian, passenger vehicle, and trucks. Searches on pedestrians may be limited to identification verification and inspection of hand carry bags, which can be accomplished very quickly as compared to the passenger vehicle or truck. Most traffic flow will be by passenger vehicles as employees arrive and depart for the work day. The limited capability to carry large quantities of explosives makes inspection of the passenger vehicle a relatively short process. Trucks which are capable of carrying larger quantities explosives will need to be thoroughly inspected. The estimated 12,000 pound bomb used in attacking the U.S. Marine Corps Barracks in Beirut, Lebanon was delivered by a stake-bed truck. [10] To prevent a backlog of traffic, and thereby reducing confusion at this entry point, the trucks should have separate inspection lanes/areas from passenger vehicles. The inspection area will need to separate from the entry point, not obstruct the traffic flow, and with each lane allowing at least 17 feet width for the vehicle and security personnel to effectively conduct the inspection. [8] Vehicles failing inspection (no employee identification, driver in wrong place, etc.) will need a rejection route away from the entry point to facilitate quick removal of the vehicle from the queue. Minimum turning radius for a passenger vehicle is 24 feet, 38 – 42 feet for trucks and busses, and 40 – 45 feet for semi trailers. [8]

Appendix C provides three designs of controlled entry points using the concepts discussed in this section. The figures in Appendix C are examples of successive increases in space and funding.

**5.0 Progressive Collapse**

Progressive collapse is a cascade of successive structural failures to the load bearing columns, beams, and walls, started by one or more structural components failing. This would be similar to how a house of cards falls down after one or two cards are removed from the bottom. The Federal building at Oklahoma City and the 2001 World Trade Center are examples of such tragedies. The design concept for new buildings greater than three stories, as well as retrofitting existing buildings, is to allow the structure to react elastically or sustain permanent damage, but still remain functionally stable to allow the evacuation of personnel and other resources. The following section provides the general concepts of progressive collapse and guidelines in preventing building collapse. For detailed information or for application to specific building systems, the knowledge of a structural engineer and blast resistance software are necessary in determining the proper results.

The following lists DoD minimum design standards to defend against imminent collapse. These standards are also conforms to ASCE Standard 7-98. In general the focus will be to design so that the arrangement of the structural elements provides stability to the entire structural system by transferring loads from any locally damaged region to adjacent regions capable of resisting those loads without collapse. [11] This is accomplished by designing the structure's members and connection points for redundancy and energy dissipating capacity (ductility and damping).

a. **Columns and Walls.** Design all exterior vertical load-carrying columns and walls to sustain a loss of lateral support at any of the floor levels by adding one story height to the nominal unsupported length. While this standard is based on the assumption of an external threat, where parking beneath buildings is unavoidable, this provision also applies to internal vertical load carrying columns and walls.

b. **Exterior Member Removal.** Analyze the structure to ensure it can withstand removal of one primary exterior vertical or horizontal load-carrying element (i.e., a column or a beam) without progressive collapse.

c. **Floors.** Design all floors with improved capacity to withstand load reversals due to explosive effects by designing them to withstand a net uplift equal to the dead load plus one-half the live load. [11]

### 5.1 Movement of Structural Members

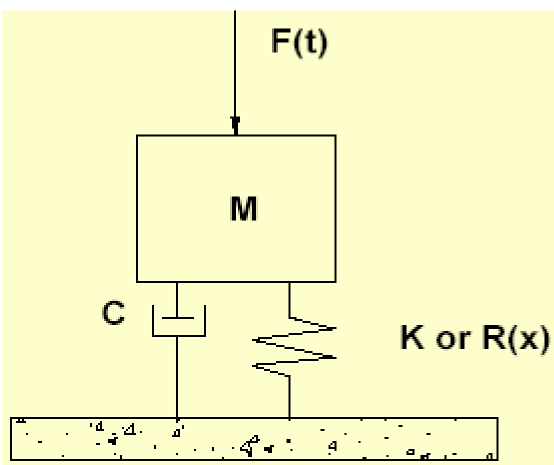



**Figure 12 – Single Degree of Freedom Model. [3]**

The same features used in designing earthquake resistance to a structure can be used on shock wave pressure. The major difference would be that the shock wave pressure would occur in fractions of a second, as compared to an earthquake that could last several minutes. In earthquake analysis the relationship between load and response is simplified with a linear model of the mass, spring, and damper. This model is also called Single Degree of Freedom (SDOF) Model. The model provides a relationship between the applied load over time F(t), mass M, damping coefficient C, and structural stiffness K or R(x). The amount of defection a member exhibits during a shock wave can be determined with empirical data on Figure 13. For a peak load P, duration T, the elasto-plastic resistance function has a plastic resistance $R_u$ reached at a yield deflection $X_e$. [3] $T_n$ is the natural period of the structure and $X_m$ is the maximum displacement. By using the applicable model of $R_u/P$ curve, and $T/T_n$, the ratio $X_m/X_e$ can then be read from the graph. The maximum deflection $X_e$ can then be calculated. The hardest part of using this graph is determining the structure's live loads (including the added design shock wave), dead loads, dampness and stiffness.

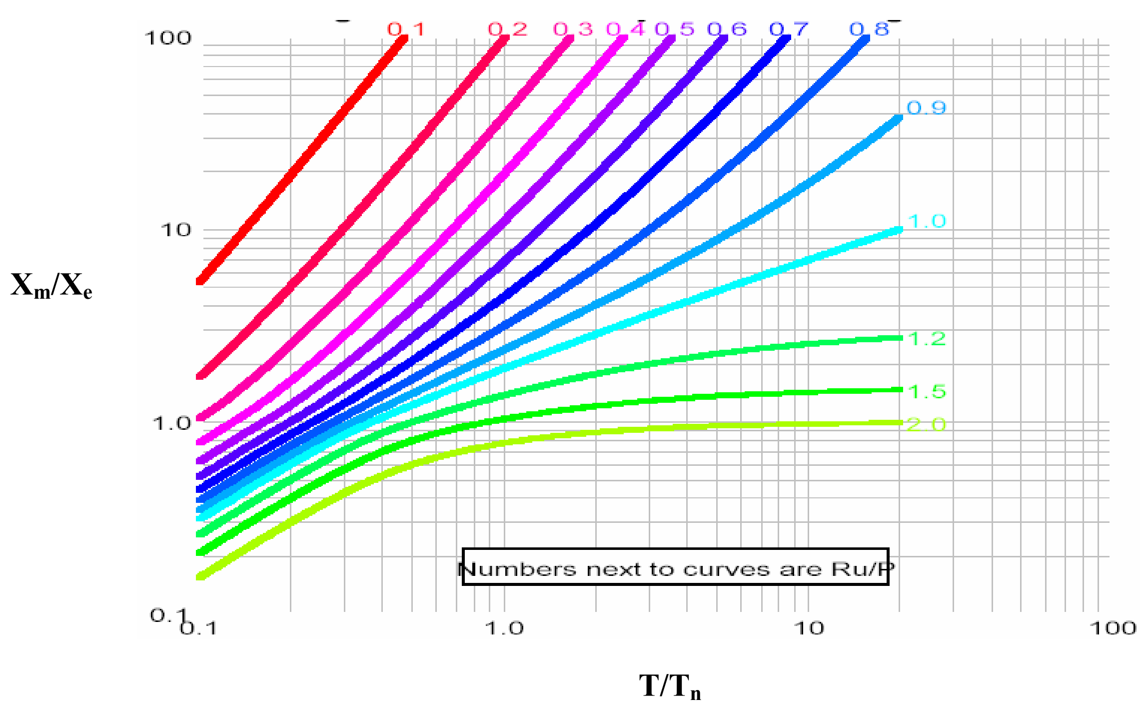



**Figure 13 – Maximum Deflection of Elasto-Plastic SDOF System. [3]**

## 5.2 Failure Mechanisms: Walls, Columns, Floor/Roof Slab

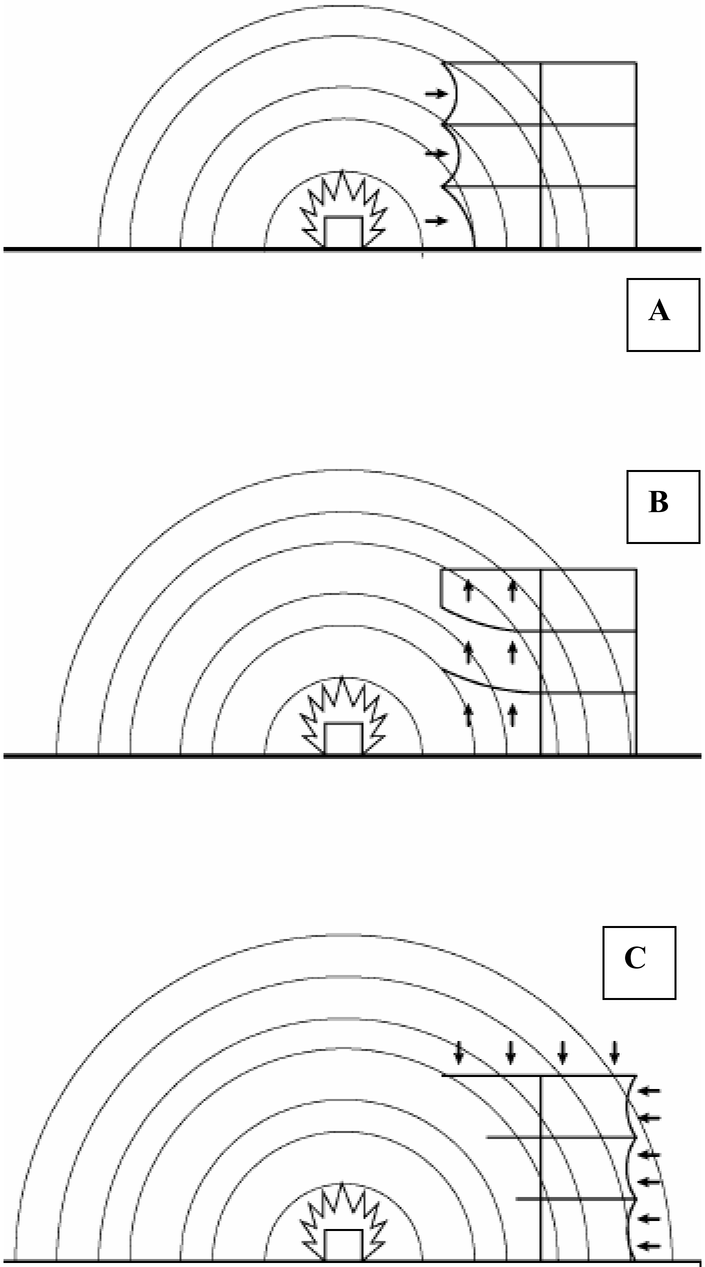



**Figure 14 – Sequence of Structural Damage with Bomb Close to Structure. [1]**

The effects of a near explosion to a structure are shown on Figure 14, each applying different failure mechanisms to the building. The shock wave first impacts the exterior walls, windows, and columns, Figure 14A. The shock wave then attacks the floor slabs, roof, columns and beams. In Figure 14B, the shock wave forces the floors and roof upward. Finally (Figure 14C) the wave completely engulfs the building, applying pressure from the roof and all walls, and attacks the building's resistance to lateral loads.

In the first phase the exterior of the building is under attack. In most structures the weakest point will be the glass cladding or windows. The other parts of the exterior of the building affected are the walls and the columns. The primary mode of failure for the load bearing walls created by the explosion is membrane/flexural (wall components are expanded like the surface of balloon) or shear (entire wall is displaced as a single unit). The load bearing walls remain under the building load, which only exacerbates the explosion failure due to membrane/flexural. To defend against such an attack, the addition of more steel into concrete or masonry unit walls is the solution. The application of equal to or greater than Building Code minimum for earthquake region, Zone 4 would have 0.25% steel in each wall face (two rows) for 10 inches thick walls, or 0.5% steel as a single row for less than 10 inches thick walls. [3] However according to the Principals of Weidlinger and Associates Consulting Engineers (WAI), more conservatism needs to be applied to both the thickness of the wall and the amount of steel for the lower level walls due to their higher vulnerability of attack. The higher level walls are less vulnerable to attack; the amount of steel in the walls can be consistent with Building Code minimums. Assuming three levels of explosive sizes WAI recommends the following steel quantities for the lower level walls:

a. To protect against a small charge weight, a nominal 12 inches thick wall with 0.3% steel doubly reinforced in both directions might be required.

b. For intermediate charge weight protection, 18 inches thick wall with 0.5% steel might be needed.

c. Finally, a large charge weight at these small standoffs will likely breach any reasonably sized wall at the lower levels. Therefore, precautions have to be taken and adjustments made for the design of the entire structure. [12]

For the columns, the shock wave attacks during the initial and middle phase. On the exterior, the columns fail in similar manner as the walls. For the interior columns, during the middle phase, uplifted forces are exerted on the floors and roof, which in turn uplift the columns as well. The similar to the solution with the load bearing walls, the addition of more steel (ties and spirals) into column design (reinforced concrete) will then lend itself to more ductility to resist the blast explosion. Since the columns are intended to only carry loads to resist gravity, the middle phase of creating uplift to the slabs will require that additional steel in the column/slab connection to resist the transient tensile forces. For steel columns, the primary need is to ensure that the exposed edges are protected from the air blast and fragments, which is accomplished with filling the space between the flanges with concrete or embedding the columns in concrete. [3]

The floor slabs and roof failure mechanism is also due to bending/membrane or shear failure, as well as crushing, Figure 15. Any failure of a floor slab and its subsequent dead load debris applied on the below floor is one form of progressive collapse. In the crushing example of Figure C, poor connections with the column can lead the slab to fall on the floor below it as a single unit.

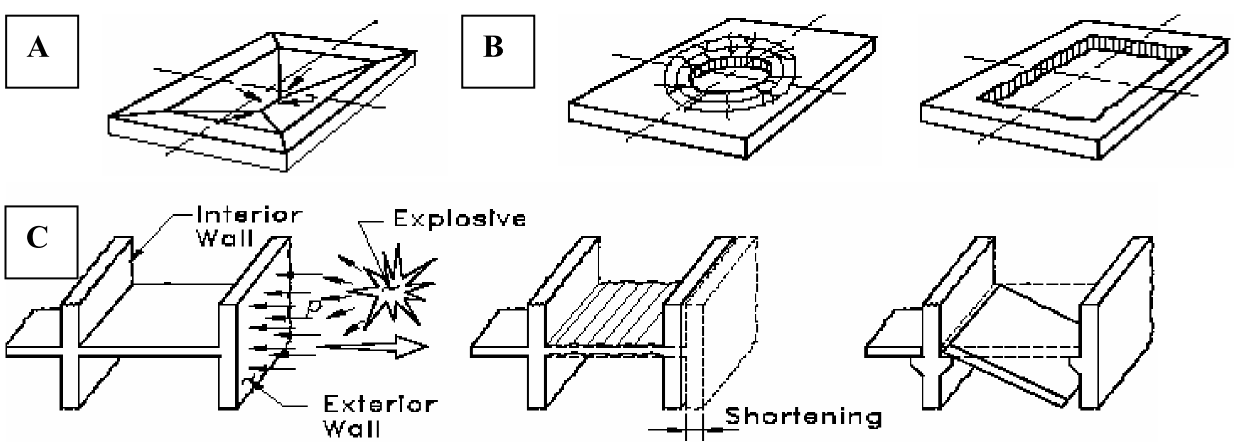



**Figure 15 – Failure Mechanisms for Slabs.**
**A: Bending/Membrane. B: Local and Global Shear. C: Crushing. [3]**

The strategies from ASCE of strengthening the floor and roof slabs to increase energy absorption are:

a. Provide sufficient top and bottom steel (reinforced concrete) to create a ductile flexural membrane response.

b. Use connections with enough capacity so that the slabs can reach the tensile-membrane response.

c. Increase the shear ductility of the slab at its support to improve the direct shear capacity.

d. Provide enough confinement (structural concrete) to achieve higher strength and more ductile concrete response. [3]

An additional strategy from Hinman and Hammond is to improve two-way slab systems by adding two more beams underneath the slab, so that the slab is supported on four sides, providing an alternate load path. [13]

Applying all of these elements as a building system, the last phase of the explosion attacks the structure's ability to resist lateral loads. Once the moment-resisting capacity of the slabs at the columns is lost, the ability of the slabs to transfer forces to the shear walls are diminished, Figure 16. [12] Additionally several broken connections between the floor slabs and columns leads to buckling of the entire length of the building column, thereby reducing the buildings lateral resistance.

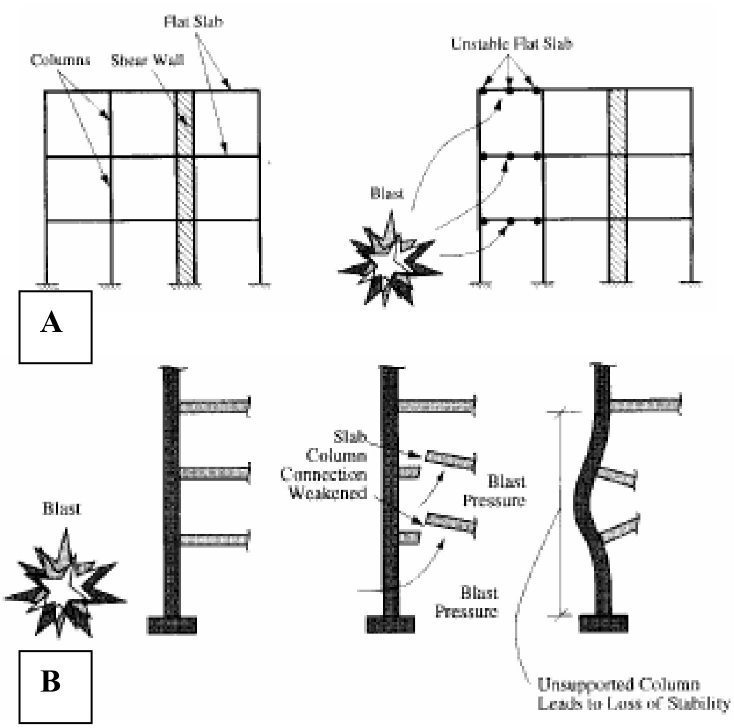



**Figure 16 – Effects on Lateral Load Resistance Mechanism. [12]**

**A: Slabs inability to transfer loads to the shear wall.**

**B: Column buckling due to loss of slab/column connection.**

Again the continuing solution for wall and columns applies as well to upgrade lateral resistance is to add more ductility to the structural members by adding more steel. Another solution is to add more shear walls; however this could be limited to the interior layout of the building, as each shear wall runs the full height of the structure. The exact amount of steel and spacing in the reinforced concrete members will need to be further detailed for the specific structure by a structural engineer and the use of blast effects software.

## 6.0 Case Studies

This section will review four terrorist attacks, of which all are from vehicle bombs (Beirut, 1993 World Trade Center, Oklahoma City, and Khobar Towers. In each case study a review of the weapons and explosives used in the attack, the existing defensive conditions at the time of attack, the damage conditions of the building, and any lessons learned. Amongst these four terrorist attacks, the Oklahoma City bombing has the most amount of unclassified information available.

### 6.1 US Marine Barracks at Beirut, Lebanon 1983

The following information is based from the Report of the DoD Commission on Beirut International Airport Terrorist Act. [10] On September 29, 1982, 1,200 US Marines and Navy personnel deployed as a Battalion Landing Team (BLT) to Lebanon. The BLT was to be part of the US Multi-National Forces (USMNF) to conduct peace keeping operations between the Lebanese army and Shiite units. What was intended to be a benign environment quickly turned volatile to the USMNF, when on April 18, 1983 a vehicle bomb exploded at the US Embassy in Beirut. On October 23, 1983 terrorists in a stake bed truck were able to penetrate the BLT's defensive perimeter. The perimeter consisted of barbed and concertina wire, hardened guard posts, and sewer pipe barriers. The truck drove through the building's entrance and was able to lodge itself into the lobby. The explosion destroyed the entire building along with the 241 sleeping Marines, sailors, and soldiers. The FBI had estimated the size of the explosive to be 12,000 pounds based on the crater dimensions, which was six to nine times greater in magnitude of the earlier US Embassy bombing.

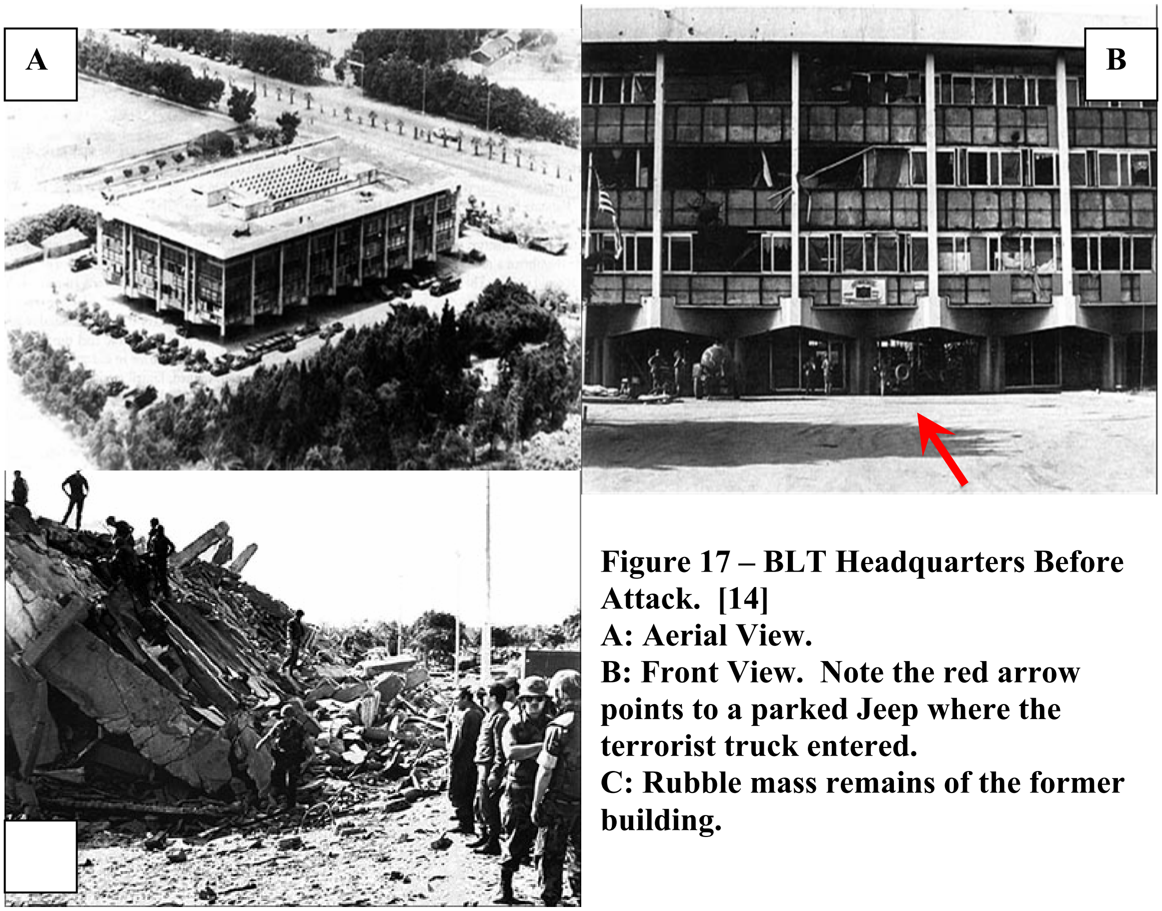



**Figure 17 – BLT Headquarters Before Attack. [14]**
**A: Aerial View.**
**B: Front View. Note the red arrow points to a parked Jeep where the terrorist truck entered.**
**C: Rubble mass remains of the former building.**

Figure 17 shows the headquarters building of the BLT before the attack and after the attack. The building is a four story reinforced concrete building located in the administrative area of the Beirut International Airport. The building had suffered fire and explosive attacks before the BLT occupied it. Most of the plate glass had been replaced with plywood, and the interior elevator was inoperable due to fire damage, otherwise the building was serviceable as their headquarters and as berthing. Entry to the building was by local roads, with the security perimeter extending 330 feet to the local roads.

There are three lessons learned from this attack that applicable to this report:

a. The USMNF were able to collect intelligence on enemy activity almost to the point of information overload. The shortfall was the inability to review all of the information and derive when, and how an attack will occur on the BLT headquarters. Additionally the earlier attack on the US Embassy set a false tone for the level of explosive weight available to the aggressors. Information on the aggressor's ability to create an even larger bomb was not available to the USMNF.

b. The perimeter defenses were primarily wire barricades and sewer pipe obstacles, reinforced with hardened guard posts. The distance from the perimeter to the headquarters building was 330 feet, providing suitable stand off distance for the smaller sized explosives capability of a passenger vehicle. To defend against the vehicle bomb threat more substantial barriers would have used such as berms and ditches, as well as concrete blocks to act as jersey barriers.

c. Exploding the truck inside of the entrance lobby, placed the truck directly next to structural and load carrying members of the building. The lesson learned is similar damage can occur with underground parking garages in urban buildings. Therefore off site parking would be preferred to maintain the effective stand off distance.

### 6.2 World Trade Center 1993

On February 26, 1993 a parked rental van exploded underneath Tower One at the World Trade Center. The van was estimated to carry 1,200 – 1,500 pounds of nitrourea, a nitrogen based fertilizer explosive, which as the equivalent weight of about 1,000 pounds of TNT. This was the first major terrorist attack in the US, which resulted in six deaths and over 1,000 injuries. The bulk of the injuries were related to smoke inhalation.[2] The elevator shafts of the high rise building acted like a chimney, allowing the smoke and heat to quickly reach the higher floors.[13] The blast epicenter was located on the B-2 Level, Figure 18. The blast created the following building damage [15]:

a. PLAZA LEVEL (three levels above the explosion)
A 100-square-foot section of concrete was cracked and lifted.

b. CONCOURSE LEVEL (two levels above the explosion)
A 400-square-foot hole was opened in a meeting/dining room near the Liberty Ballroom of the Vista Hotel.

c. B-1 LEVEL (one level above the explosion)
A 5,000-square-foot hole was opened on the ramp leading to the parking garage below. Elevators were damaged and not operational. Seven steel columns appeared damaged and left without lateral support.

d. B-2 LEVEL (ground zero)
An L-shaped crater, approximately 130 by 150 feet at its maximum points, was opened, collapsing reinforced concrete and debris onto levels below. At least nine steel columns appeared damaged and left without lateral support. Utilities and fire protection on this level were damaged and not operational.

e. B-3, B-4, B-5, B-6 LEVELS (below the explosion)
Debris from the blast traveled through a three-level architectural opening (spanning levels B-3 through B-5) and crashed down on refrigeration equipment on B-5. Utilities and fire protection on these levels were damaged and not operational. Flooding on B-6 due to rupture of cooling water lines.

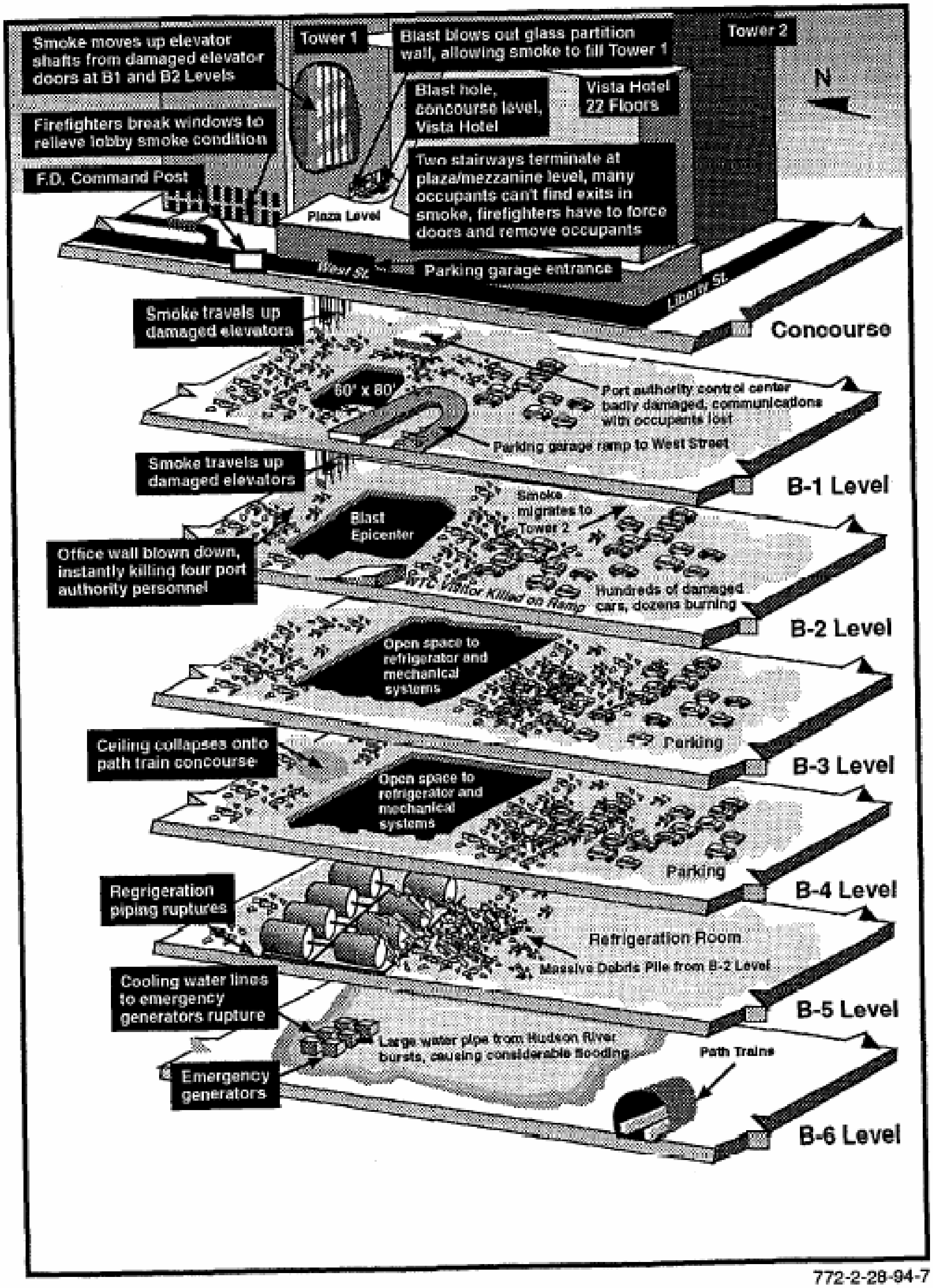



**Figure 18 – 1993 World Trade Center Blast Damage. [16]**

Though the floor slab damage listed above is substantial, the main supporting column nearest to the blast did not buckle, Column 324. Column 324 is a steel column (4 feet by 4 feet in cross section) had lost its fire proofing and its lateral restraint (i.e. the bracing provided by two concrete floors that were blown out around it), but was not otherwise damaged by the explosion. [2] The nearby columns showed the same cosmetic damage. If this column had buckled, building collapse would have been imminent as the base of the structure would have been compromised.

The applicable lessons learned from this attack:

a. Eliminate vehicle parking underneath the structure. A vehicle bomb exploding underneath a structure would be directly attacking the buildings foundation and columns that support the entire structure.

b. Electrical power for stairwell lighting was damaged during the attack. Battery operated lighting and use of phosphorescent signs/paint in the stairwells would allow faster egress of building occupants. Approximately 50,000 people were evacuated from the World Trade Center Complex. [16]

c. All utilities, fire protection, and phone service was damaged during the attack. Installing redundant systems would ensure such services would remain operational after an attack. Rescue personnel would then be able to use the building's systems for more efficient evacuation of mobile building occupants and the rescue of trapped personnel.

d. Locate the elevator service shafts away from underground the underground parking garage. The elevator shafts acted as chimneys in spreading the heat and smoke to the upper levels of the tower.

### 6.3 Murrah Federal Bldg, Oklahoma City 1995

The attack on the Alfred P. Murrah Federal building was the first major terrorist attack in the US by domestic terrorists. On April 19, 1995 a truck carrying 4,000 pounds of explosives detonated on the North side of the Murrah building. The explosion killed 168 people, injured more than 500 people, and it is estimated that greater than 80% of the fatalities were caused by the building collapse rather than the blast itself. [19] The crater size was 28 feet in diameter and 6 feet – 8 inches deep.


**Figure 19 – North View of the Damaged Murrah Building. [23]**

**Rescue and debris removal completed, the building is prepared for demolition.**

The building was the working space to 19 Federal Agencies to include the Social Security Administration, Veterans Administration and Drug Enforcement Administration. The Murrah building was a nine story reinforced concrete building. The North side of the building had curbside access and loading zone. The South side of the building faced a courtyard of trees, bushes, and concrete pathways leading to the main entrance of the building. Both the North and South sides of the building were cladded with full floor height glass. The four corners of the building had large cylindrical concrete air ducts. The stair wells and elevator shafts protruded out on the South side of the building.

On the North side, along column line G, four free standing columns (36 inches by 20 inches cross section) supported the building, Figure 20. These four columns were exposed and spanned from the 1$^{st}$ floor to the 3$^{rd}$ floor with out any lateral support. At the 3$^{rd}$ floor the main columns transitioned to transfer girders (5 feet by 3 feet cross section). The transfer girders spanned the full width of the North side. The girders then supported eleven intermediate columns that spanned up to the top 9$^{th}$ floor. Lateral support of the intermediate columns between 4$^{th}$ floor to the 9$^{th}$ floor were by the floor slabs. Transitioning the nine intermediate columns down to four larger main columns, as well as exposing the four main columns was to provide architectural appeal of an open entry of the North side. However, it reduced the redundancy of the design so that the loss of a single transfer girder would collapse a 40 feet by 35 feet area or the loss of a single main column would collapse a 80 feet by 35 feet. [13]

The truck bomb was parked 10 feet away from the building and column G20 was the closest to the epicenter. The explosion collapsed nearly one half of the building, as shown on Figure 21. Three of the four main columns collapsed, G16, G20, and G24. The lone remaining primary column was G12. The collapse of the three main columns brought down the successor intermediate columns and tributary floor slabs. F24, an interior column collapsed bringing down its tributary bays. This provides the additional "dented" appearance to the collapsed area.

Column G20 being closest to the epicenter failed due to brisance, or was shattered by the explosion. The estimated peak pressure experienced by column G20 was 5,600 psi. [20] Columns G24 and G16 failed due to shear at the connection point of the ground floor and at the connection of the 3$^{rd}$ floor transfer girder. Column G24 experienced peak pressure of 1,400 psi and would have deflected 2.2 inches, while column G16 experience peak pressure of 641 psi and would have deflected 1.2 inches.[20] The expected shear failure of the columns would have only required a deflection of 1.0 inches. The 3rd through 5th floor slabs between columns G20-G22, which were in direct proximity of the blast experienced an upward lift as much as 154 psi.[20] Since the slabs were designed for gravity or downward loads, the steel in the floor slabs were matted only on the bottom face. With no steel on the top face of the slab, the shock wave pressure uplifting the slab exceeded its capacity for deflection. Figures 22 and 23 show the extent of the shock wave damage to the columns and slabs. The successive columns and floor slabs above the blast dependent damage, was the result of progressive collapse.

The applicable lessons learned from this attack are as follows:

a. Though the South and main entrance to the building had substantial stand off distance because of the courtyard, the North side of the building was directly exposed to attack with the stand off distance only being the width of the sidewalk, 10 feet. The stand off distance would need to fully encapsulate the perimeter of the building. However in urban situations as this and as in Washington D.C., creating extensive stand off distances is not practical. However stand off can be accomplished as shown by the NCPC by removing street parking and installing streetscape barriers such as bollard, planters, and permanent benches.

b. Exposure and loss of redundancy of the primary columns exposed the building's weakness. The lesson learned is the opposite of the Murrah building design, by designing redundancy into the building system.

c. Limit the glass cladding from the street level. Since the bottom floors are the most vulnerable to vehicle bomb attacks, reinforced walls should be used instead of the full floor height glass of the Murrah building.  The glass provided no protection from the shock blast.

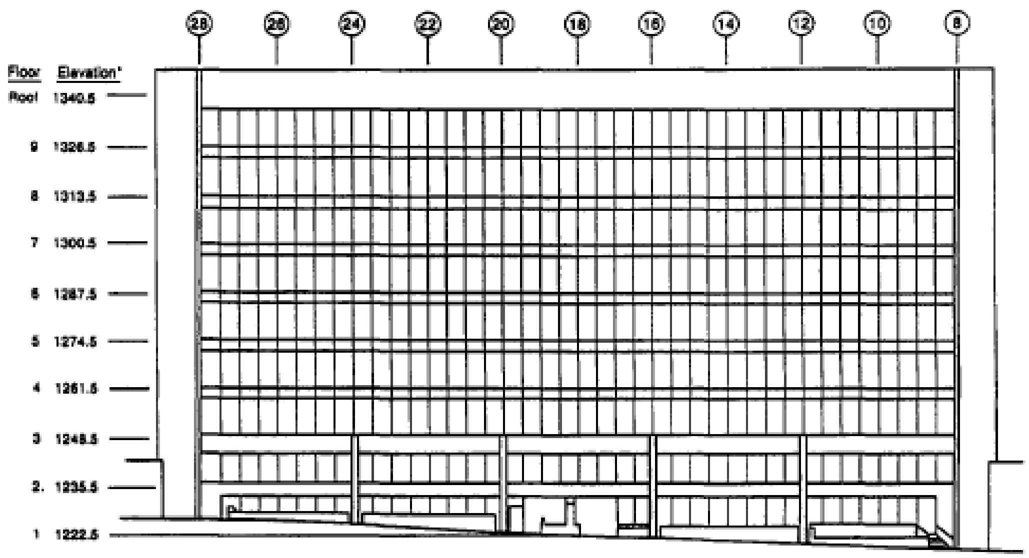



**Figure 20 – North Elevation View of the Murrah Building. [21] Note the four main columns and the 3rd floor transfer girders.**

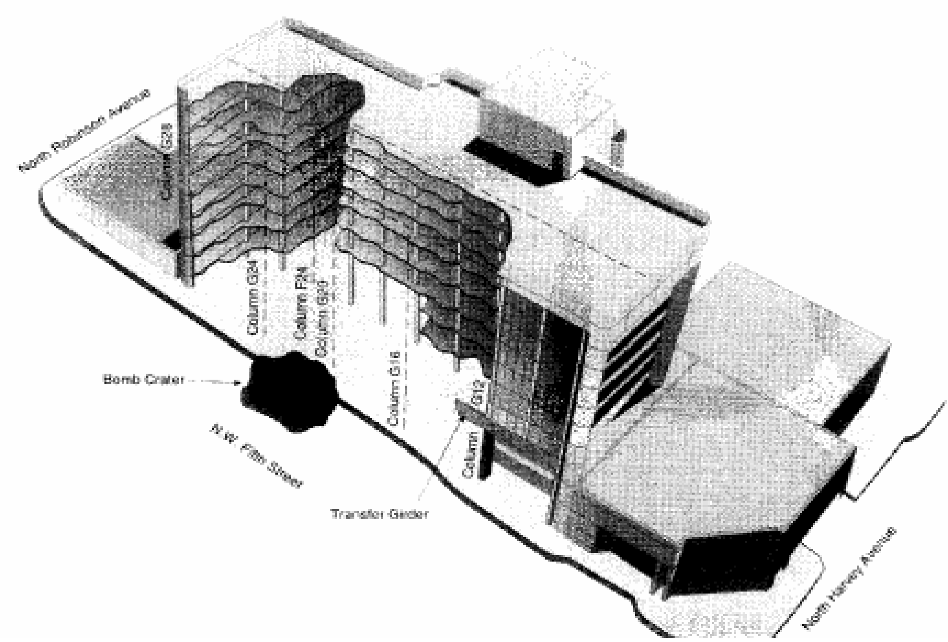



**Figure 21 – Explosive Damage to the North Side of the Murrah Building. [22]**

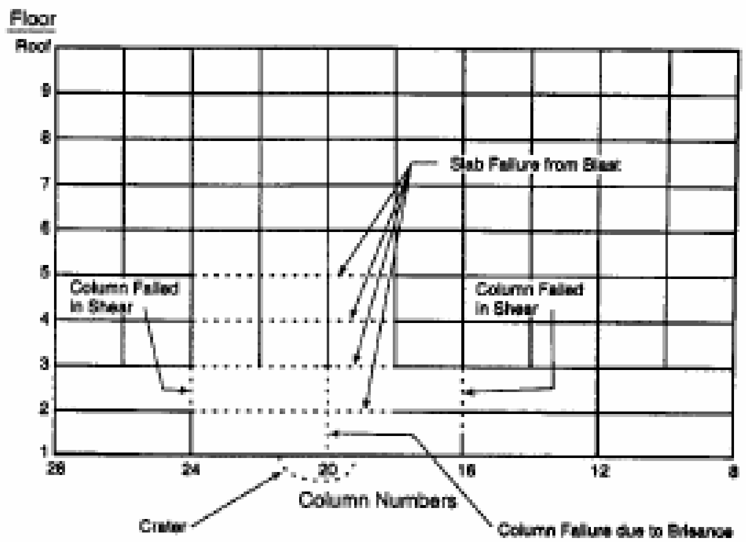



**Figure 22 – Schmatic of Blast Response, North Elevation of Nine Story Portion of Murrah Building at Column Line G. [20]**

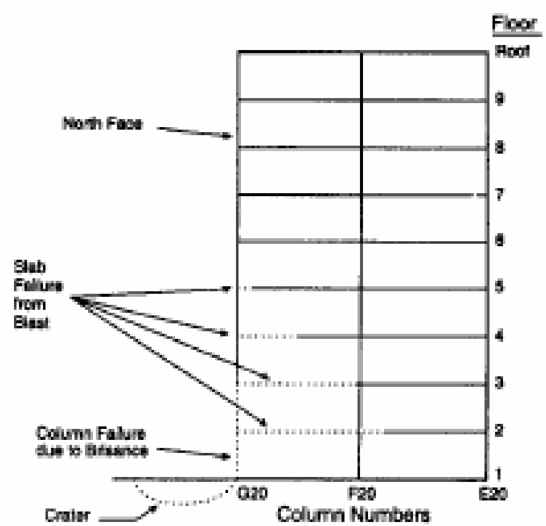



**Figure 23 – Cross Section of Nine Story Portion of Murrah Building Showing Blast Response of the Slab. [20]**

### 6.4 Khobar Towers, Saudi Arabia 1996

Coalition force deployed to Saudi Arabia comprised of armed forces from the US, UK, France and Saudi Arabia participating in Operation Southern Watch, United Nations effort to enforce the no-fly and no-drive zones in Iraq south of the 32$^{nd}$ parallel. [17] The Khobar Towers complex are a series of high rise apartments that housed the deployed units. The apartments were constructed with reinforced concrete. The perceived threat to US personnel was considered low, as thousands of US oil workers have lived in Saudi Arabia for years without any incident. On November 13, 1995 a terrorist bomb carrying approximately 250 pounds of explosives detonated outside the Office of the Program Managager, Saudi Arabian National Guard (OPM-SANG). The OPM-SANG building was used by US military to train the Saudi military. The attack on the OPM-SANG quickly changed the threat level for the US military. Security improvements on the Khobar Towers began to include the placement of concrete jersey barriers and concertina wire around the perimeter, trimming vegetation around the perimeter, installation of barriers to create a serpentine route to the main entrance, posting of guards on the roof tops, and increase of security patrols of the perimeter. [17] The existing perimeter on the North section of the Khobar towers was at 80 feet. Discussions with the host nation to increase this distance to 100 feet was denied due to the impact of the adjacent public parking lot. [18] Layout of the Khobar Towers and the location of US, UK, French and Saudi berthing relative to the bomb attack are shown Figure 24. US Air Force 4404$^{th}$ Fighter Wing occupied these apartments.

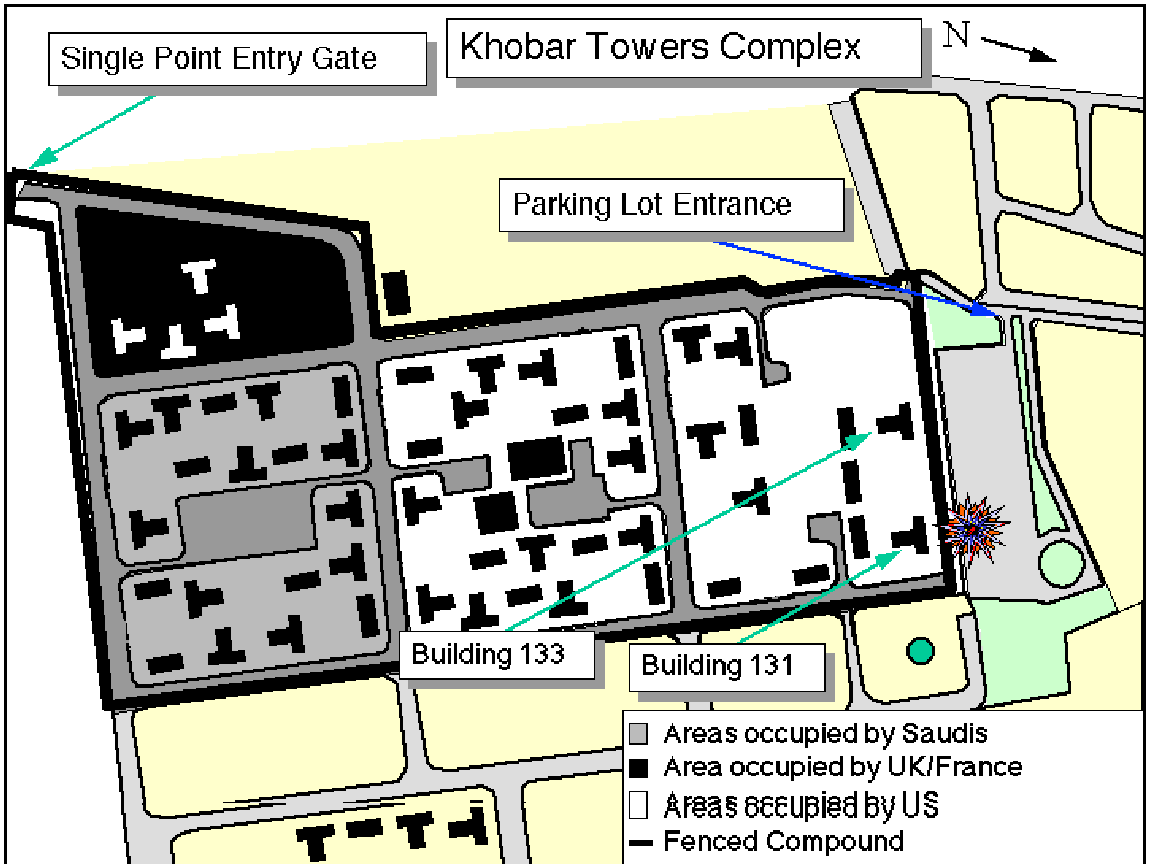



**Figure 24 – Location of US, UK, French, and Saudis Personnel at the Khobar Towers Complex, Relative to Bomb Attack. [18]**

June 25, 1996 roof top guards observed a fuel truck and passenger vehicle parked at the North end of the perimeter, near building 131. The driver of the fuel truck abandoned his vehicle and departed the area in the passenger vehicle. Roof top guards then began evacuating personnel in building 131 by knocking door to door. The fuel truck exploded damaging building 131 and the adjacent buildings, leaving a crater approximately 85 feet by 35 feet deep, Figure 25. Luckily many of the evacuating residents were in the building's stairwell at the time of the explosion, which may have been the safest place to be, in the estimation of the engineers and security experts on scene. [17] The resultant blast killed 19 US personnel, with 200 personnel with injuries.

The size of the bomb was estimated to be approximately 4,000 pounds based on the crater and blast damage.

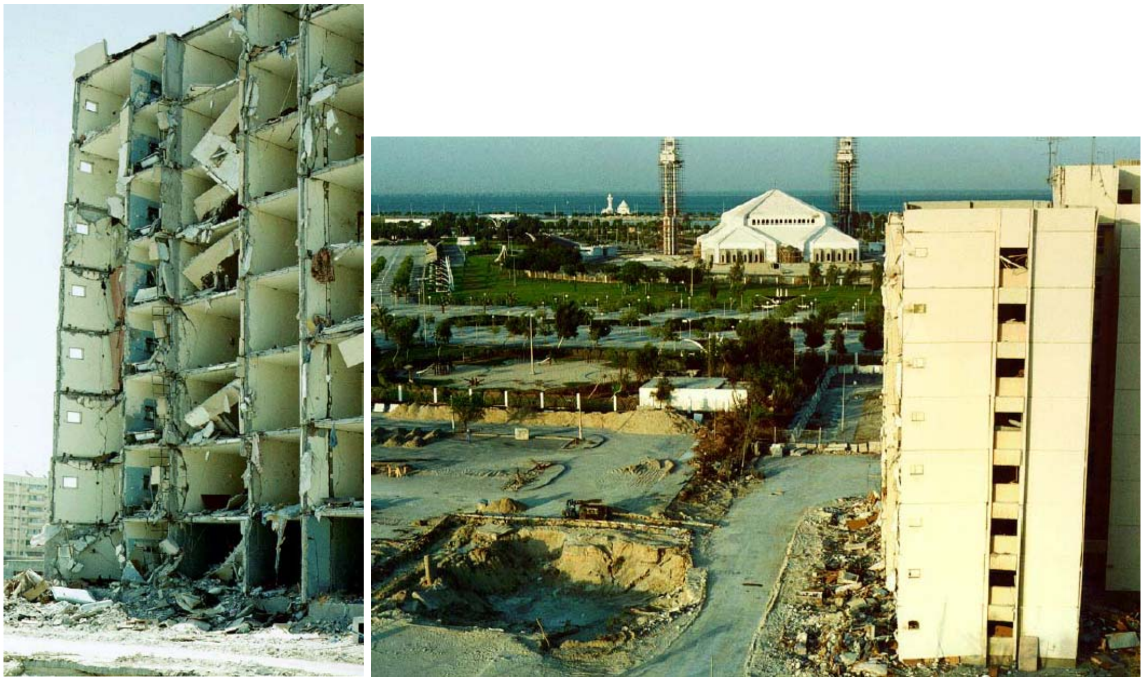


**Figure 25 – Blast Damage to Building 131.  [17]**
**Left:  Front View.  Right:  Crater (85 feet by 35 feet deep).**

The applicable lessons learned from this attack:

a. The majority of the injuries suffered were from flying glass debris.  Application of glazing or tempering of the windows, or the use of blast curtains would have limited the amount of injuries.  According to the Task Force experts, if a smaller sized bomb was used, such as the 200 pound bomb at OPM-SANG, similar extensive injury would have occurred due to flying glass fragments. [18]

b. Similar to the lesson learned for the Beirut attack, collection of intelligence on terrorist actions was not the problem, rather the shortfall of interpretation of the reports to detail the location and method of an imminent attack.

c. The perimeter jersey barriers were effective in keeping the truck bomb outside of the perimeter at 80 feet. However the 80 feet stand off was based on the lesser explosive carrying capability of passenger vehicles.

**7.0 Conclusions**

Terrorist organizations chose to operate in a clandestine environment, however data collection on their past activity as well as current operations are available from national intelligence organizations down to local police departments. As seen from the above case studies the talent is not the collection of the data, rather the interpretation leading to knowledge of the timing and method of an attack.

If an organization feels that their facilities and assets could be the next target of a major terrorist attack, the first step is to collect the latest intelligence on perceived threats and develop the defensive protection plans. Once the threat levels have been defined, then designing the defense will only limited by the organizations constraints (funding, space, etc.).

The most cost effective defense is establishing a perimeter with adequate stand off distance to the critical facilities. The installation of barriers, controlled entry points, and security patrols are effective for military installations, however for facilities within an urban environment, the luxury of large open fields for their perimeter is not available. At the very least street side parking and underground parking should be eliminated. Increasing the pedestrian path on the street and installing functional barricades such as curbing, trees, planters, permanent benches, decorative fencing, and bollards improves the standoff distance while creating a friendlier “streetscape”.

The most expensive aspect of the defense is hardening the facility.  However the construction of a fortress is not an acceptable solution.  Improving the ductility of the building's structural members and including redundancy prevents progressive collapse. These structural improvements may already be included in the facilities that are rated for earthquake or typhoon/hurricane resistance.

**Appendix A: Damage to Various Building Types Based on Computer Simulation by Explosive Risk and Structural Damage Assessment Code (ERASDAC), Blast Damage Assessment Model (BDAM) and the Facility and Component Explosive Damage Assessment Program (FACEDAP). [1] [9]**

Certain types of construction are highly blast resistant while others are not. Damage is prevalent for wood construction to large distances, caused by the inherent fragility of wood components. Conversely, reinforced concrete frames offer a high level of blast resistance, even though some thin panels used to fill in between structural columns may be destroyed. It is difficult to produce total destruction in this type of construction since these components provide a high level of resistance.

The size of the structure relative to the bomb size is a significant factor in the amount of damage produced. The type of construction and the size of the weapon are other key factors. Reinforced concrete can be expected to perform better than masonry; however, a small, strong masonry building may withstand damage better than a large, two-story, lightly reinforced concrete building.

**Table A-1: Structural Damage Description Categories**

| Damage Level | Percent Damaged* | Damage Description | Repairable/ Reusable |
|---|---|---|---|
| **Severe** | **60 to 100** | **Frame collapse/massive destruction. Little left standing.** | **No** |
| **Heavy** | **40 to 60** | **Large deformation of structural members. Major nonstructural component damage.** | **Very unlikely** |
| **Moderate** | **20 to 40** | **Some deformation of structural members, and extensive nonstructural damage.** | **Possible** |
| **Minor** | **10 to 20** | **Little or no damage to major structural members, some damage to nonstructural.** | **Most probably** |
| **Minimal** | **0 to 10** | **Window damage extensive, light or local damage to nonstructural members.** | **Yes** |

**Table A-2: Large One Story Wood Building**

Large one-story wooden building 7,200 square feet floor space, 120 feet by 60 feet with 10 feet height. Interior columns, stud walls, plywood sheathing, and decking.

| Charge Weight (lbs) | Distance for Specified Damage and Injury (ft) | | | | |
|---|---|---|---|---|---|
| | Minimal | Minor | Moderate | Heavy | Severe |
| 50 | 300 | 150 | 95 | 20 | --- |
| 220 | 600 | 400 | 220 | 100 | 15 |
| 500 | 850 | 660 | 360 | 145 | 40 |
| 1,000 | 1,100 | 950 | 560 | 200 | 70 |
| 4,000 | 1,400 | 1,300 | 1,250 | 350 | 125 |
| 40,000 | 3,500 | 3,250 | 3,125 | 850 | 280 |

**Table A-3: Large Two Story Wood Building**

Two-story wooden building 1,600 square feet floor space, 32 feet by 25 feet with stud load bearing walls, plywood roof decking, asphalt shingles, plank sheathe siding.

| Charge Weight (lbs) | Distance for Specified Damage and Injury (ft) | | | | |
|---|---|---|---|---|---|
| | Minimal | Minor | Moderate | Heavy | Severe |
| 50 | 130 | 80 | 61 | 52 | 25 |
| 220 | 375 | 159 | 151 | 115 | 48 |
| 500 | 580 | 270 | 220 | 162 | 65 |
| 1,000 | 875 | 460 | 270 | 210 | 95 |
| 4,000 | 1,450 | 1,060 | 480 | 310 | 175 |
| 40,000 | 3,500 | 2,600 | 1,000 | 650 | 380 |

**Table A-4: Prefabricated Steel Building**
One-story pre-engineered metal, 1,600 square feet, 20 feet by 80 feet. Steel frames at 20 feet, corrugated metal roof on purlins.

| Charge Weight (lbs) | Distance for Specified Damage and Injury (ft) | | | | |
|---|---|---|---|---|---|
| | Minimal | Minor | Moderate | Heavy | Severe |
| 50 | 85 | 68 | 53 | 35 | 20 |
| 220 | 165 | 130 | 102 | 83 | 53 |
| 500 | 250 | 200 | 165 | 130 | 90 |
| 1,000 | 380 | 295 | 230 | 195 | 145 |
| 4,000 | 780 | 620 | 470 | 400 | 300 |
| 40,000 | 2,450 | 2,050 | 1,420 | 1,220 | 750 |

**Table A-5: Unreinforced Concrete Masonry Unit (CMU) Building**
One-story building 1,600 square feet, 20 feet by 80 feet with 12 feet height. Unreinforced concrete moment frame and CMU infill walls. Lightweight reinforced concrete for the roof.

| Charge Weight (lbs) | Distance for Specified Damage and Injury (ft) | | | | |
|---|---|---|---|---|---|
| | Minimal | Minor | Moderate | Heavy | Severe |
| 50 | 205 | 145 | 115 | 90 | 20 |
| 220 | 340 | 260 | 195 | 165 | 56 |
| 500 | 450 | 350 | 270 | 230 | 100 |
| 1,000 | 630 | 465 | 375 | 310 | 150 |
| 4,000 | 1,130 | 780 | 585 | 510 | 320 |
| 40,000 | 3,000 | 2,100 | 1,620 | 1,520 | 820 |

**Table A-6: Reinforced Concrete Masonry Unit (CMU) Building**
One-story building 1,600 square feet, 20 feet by 80 feet with 12 feet height. Reinforced concrete moment frame and CMU infill walls. Roof lightweight reinforced concrete.

| Charge Weight (lbs) | Distance for Specified Damage and Injury (ft) | | | | |
|---|---|---|---|---|---|
| | Minimal | Minor | Moderate | Heavy | Severe |
| 50 | 80 | 55 | 25 | --- | --- |
| 220 | 145 | 100 | 65 | 30 | --- |
| 500 | 220 | 155 | 100 | 55 | 10 |
| 1,000 | 340 | 220 | 140 | 85 | 50 |
| 4,000 | 610 | 390 | 270 | 180 | 115 |
| 40,000 | 1,500 | 1,050 | 690 | 580 | 350 |

**Table A-7: One Story Reinforced Concrete Building**
One-story building 9,600 square feet floor space, 60 feet by 160 feet with 12 feet ceiling. The building has reinforced concrete load bearing walls and columns. The roof is lightweight concrete over open-web steel joists.

| Charge Weight (lbs) | Distance for Specified Damage and Injury (ft) | | | | |
|---|---|---|---|---|---|
| | Minimal | Minor | Moderate | Heavy | Severe |
| 50 | 90 | 30 | --- | --- | --- |
| 220 | 160 | 140 | 110 | 50 | --- |
| 500 | 250 | 215 | 170 | 130 | 20 |
| 1,000 | 350 | 290 | 260 | 195 | 90 |
| 4,000 | 780 | 600 | 560 | 495 | 150 |
| 40,000 | 2,500 | 2,000 | 1,850 | 1,630 | 500 |

**Table A-8: Two Story Reinforced Concrete Building**
Two-story building 1,800 square feet floor space, 30 feet by 30 feet with 14 feet story height. Eight-inch reinforced concrete load bearing walls, 4-inch lightweight concrete roof. Interior columns.

| Charge Weight (lbs) | Distance for Specified Damage and Injury (ft) | | | | |
|---|---|---|---|---|---|
| | Minimal | Minor | Moderate | Heavy | Severe |
| 50 | 90 | 38 | 10 | --- | --- |
| 220 | 210 | 100 | 78 | 35 | --- |
| 500 | 360 | 175 | 130 | 55 | 32 |
| 1,000 | 520 | 245 | 195 | 105 | 45 |
| 4,000 | 1,120 | 570 | 460 | 255 | 110 |
| 40,000 | 3,000 | 1,900 | 1,500 | 1,010 | 440 |

**Table A-9: Steel Frame with Reinforced Concrete Masonry Unit Building**
Two-story building with 14,000 square feet floor area, 100 feet by 70 feet, 12 feet story. Steel frame with reinforced CMU infill walls. Corrugated metal roof on open web joists.

| Charge Weight (lbs) | Distance for Specified Damage and Injury (ft) | | | | |
|---|---|---|---|---|---|
| | Minimal | Minor | Moderate | Heavy | Severe |
| 50 | 70 | 50 | 20 | 10 | --- |
| 220 | 155 | 90 | 65 | 40 | 15 |
| 500 | 260 | 135 | 95 | 65 | 30 |
| 1,000 | 400 | 190 | 145 | 105 | 65 |
| 4,000 | 930 | 450 | 340 | 275 | 102 |
| 40,000 | 3,100 | 1,650 | 1,350 | 830 | 300 |

**Table A-10: Steel Frame and Glass Building**
Multi-story building steel frame with glazing window curtain walls.

| Charge Weight (lbs) | Distance for Specified Damage and Injury (ft) | | | | |
|---|---|---|---|---|---|
| | **Minimal** | **Minor** | **Moderate** | **Heavy** | **Severe** |
| 50 | **309** | **195** | **147** | **10** | --- |
| 220 | **506** | **319** | **241** | **40** | **15** |
| 500 | **665** | **420** | **317** | **65** | **30** |
| 1,000 | **840** | **530** | **400** | **115** | **65** |
| 4,000 | **1,300** | **839** | **633** | **275** | **135** |
| 40,000 | **2,850** | **1,800** | **1,350** | **400** | **300** |

## Appendix B: Examples of Active Barriers. [1]

### Table B-1: Department of State Approved Active Barriers.

| Manufacturer | Ref. # | Model | DOS Ratings* |
|---|---|---|---|
| Crisp and Associates | 1 | VSB 80187 P10 | K12/L1 |
| 272 Airport Road | 2 | VSB 80187-10 | K12/L3 |
| Oliver Springs, TN 37840 | | | |
| Office: (423) 435-6602 | | | |
| Delta Scientific Corporation | 3 | TT207(S) | K12/L1 |
| 24901 West Avenue Stanford | 4 | TT210 | K4/L2 |
| Valencia, CA 91355 | 5 | TT280 | K12/L2 and K8/L3 |
| Office: (805) 257-1800 | | | |
| FAX: (805) 257-0617 | | | |
| Nasatka Barrier, Inc. | 6 | NMSBII | K12/L3 |
| 8405 Dangerfield Place | 7 | NMSBIIIb | K12/L3 |
| Clinton, MD 20735 | 8 | NMSBIV | K12/L3 |
| Office: (301) 868-0300 | 9 | NMSBVIIa | K8/L3 |
| FAX: (301) 868-0524 | | | |
| OMNISEC Security Systems Inc. | 10 | Magnum | K12/L3 |
| 8000 Westpark Drive, Suite 2000 | 11 | Portapungi | K8/L1 |
| McLean, VA | 12 | De-Fender | K4/L2 |
| Office: (703) 318-8226 | 13 | Stinger | K12/L3 |
| FAX: (703) 318-9341 | | | |

*Ratings (based on 15,000-lb vehicle weight):

| <u>Speed of Vehicle at Impact</u> | | <u>Maximum Allowable Penetration of Vehicle</u> |
|---|---|---|
| K12 = 50 mph | (KE= 1,250,000 ft-lb) | L3 = 3 feet |
| K8 = 40 mph | (KE= 800,000 ft-lb) | L2 = 3 to 20 feet |
| K4 = 30 mph | (KE= 450,000 ft-lb) | L1 = 20 to 50 feet |

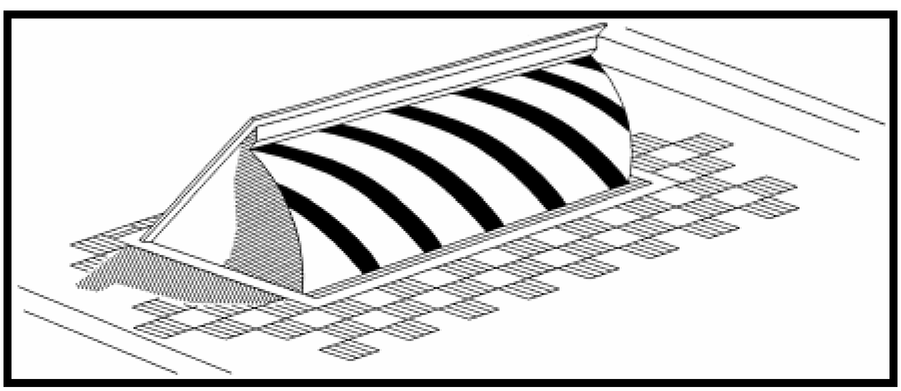


**Figure B-1: Barrel Type Barricade.**

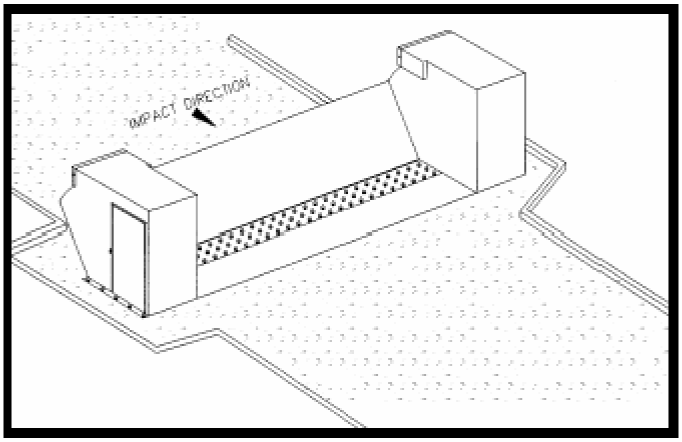


Figure B-2: Lift Plate Barricade.

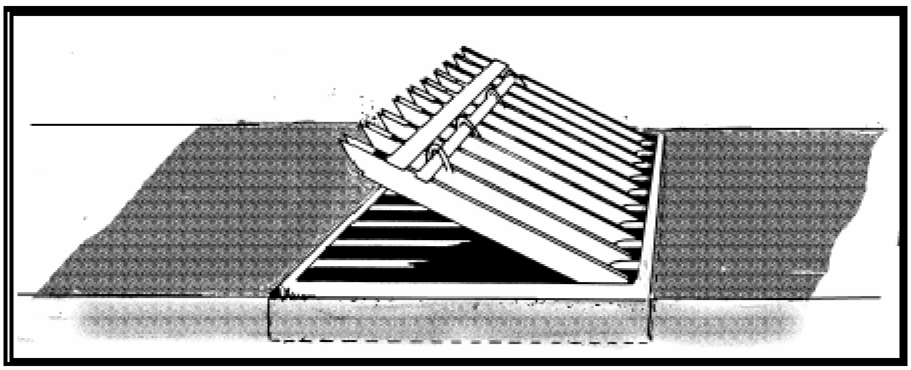


Figure B-3: Beam Type Barricade.

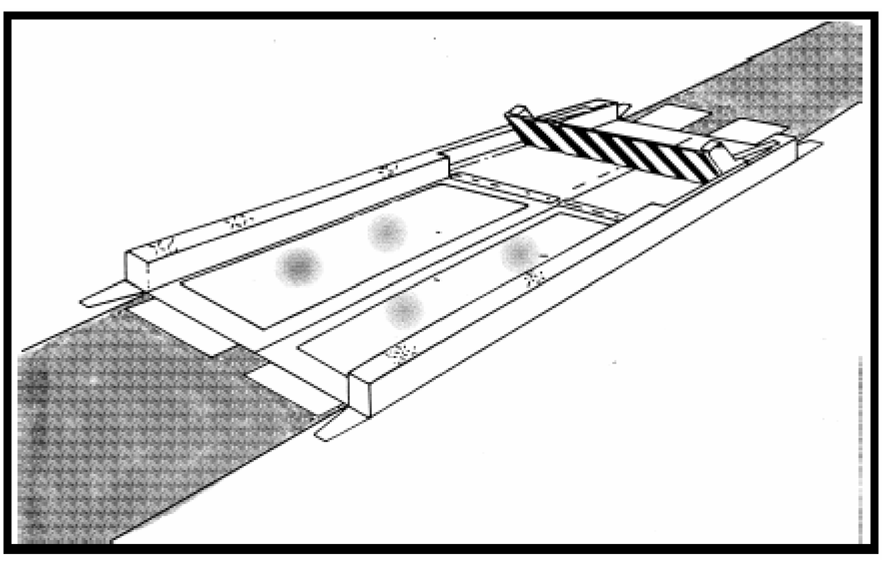


Figure B-4: Portable Type Barricade.

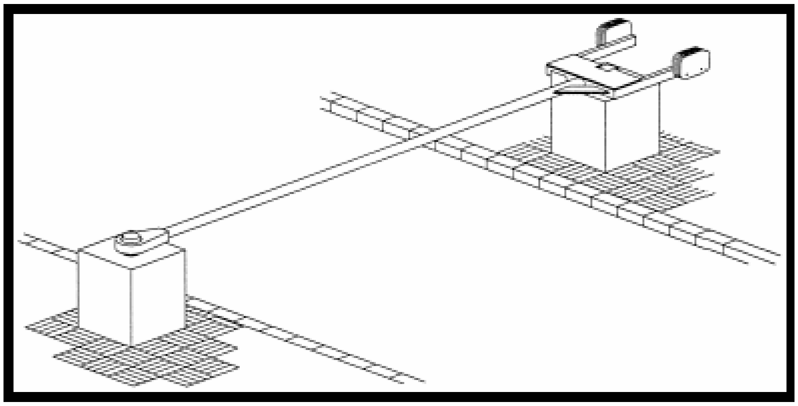


Figure B-5: Cable Reinforced Drop Gate.

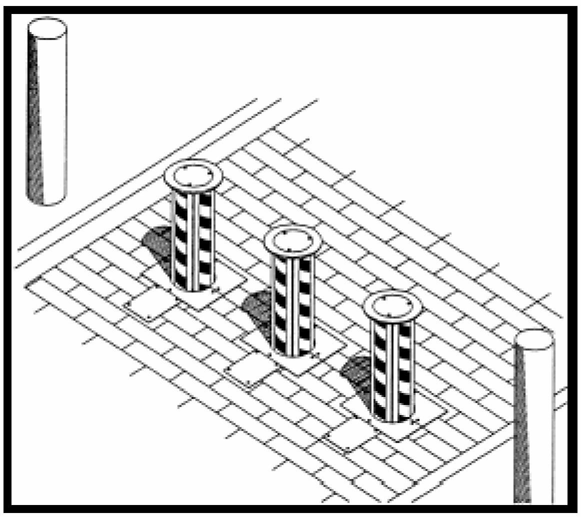


Figure B-6: Hydraulic Bollards.

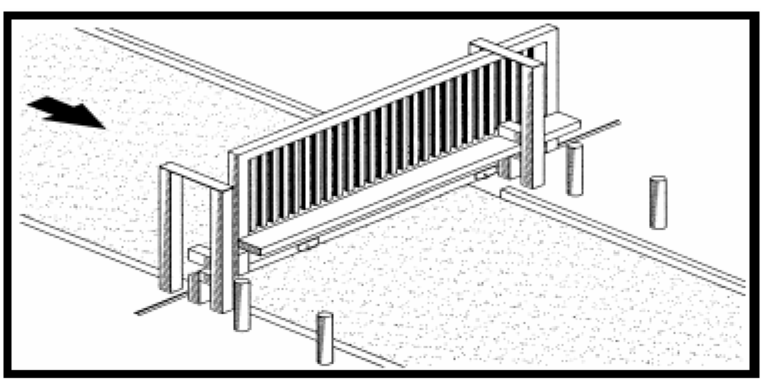


Figure B-7: Beam Type Gate.

**Appendix C: Examples of Effective Controlled Entry Point Designs. [8]**

**Figure C-1: Constrained Design With Limited Space and Funds.**
Note that traffic speed is not impeded until very close to the first guard booth. Since the space is limited, the design is dependent on the passive barrier in front of the first guard booth to crash a high speed vehicle attack.

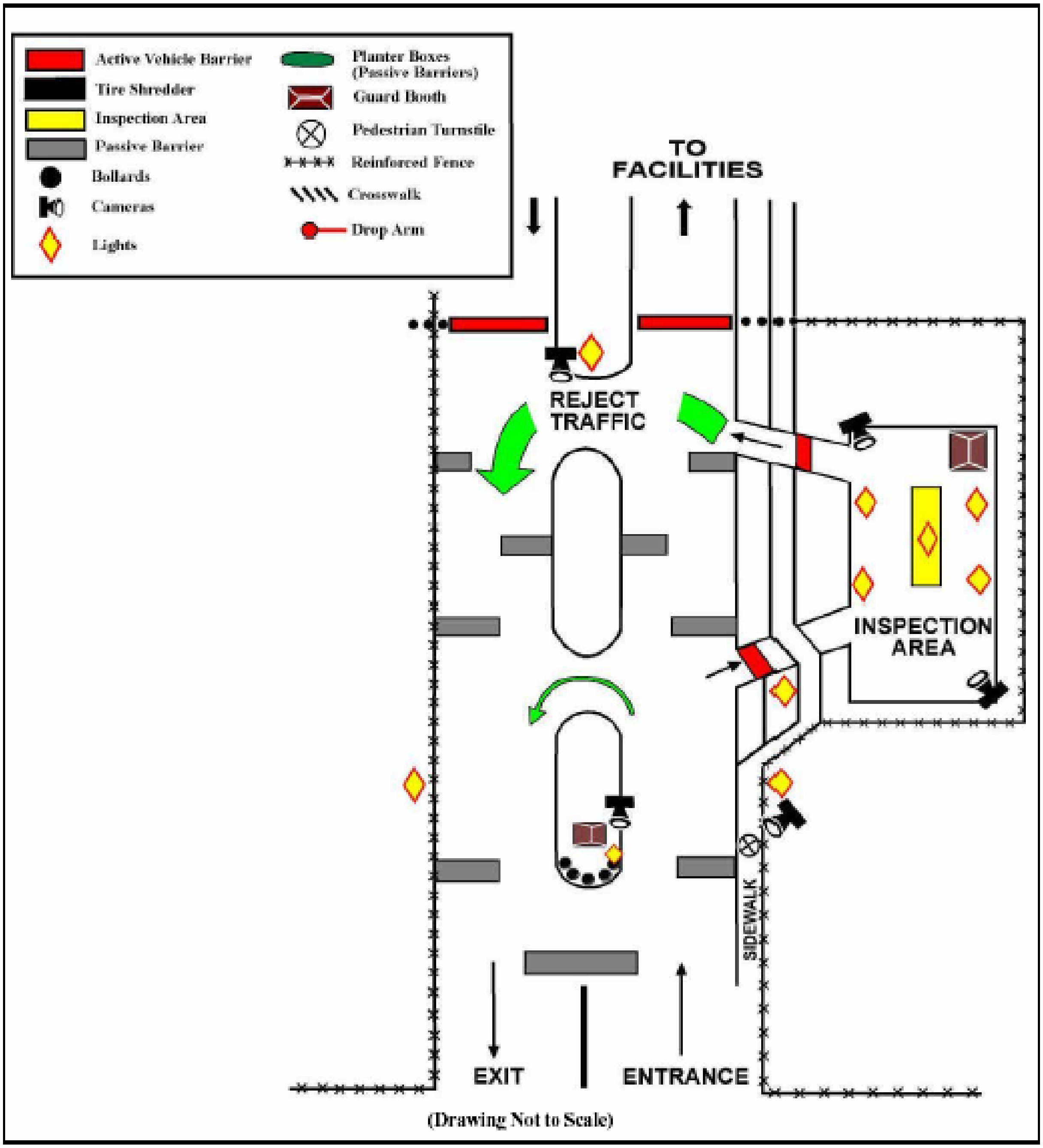


**Figure C-2: Partially Constrained Designed With Limits on Space or Funding.** Note the use of curves to reduce traffic speed before approaching the guard booth.

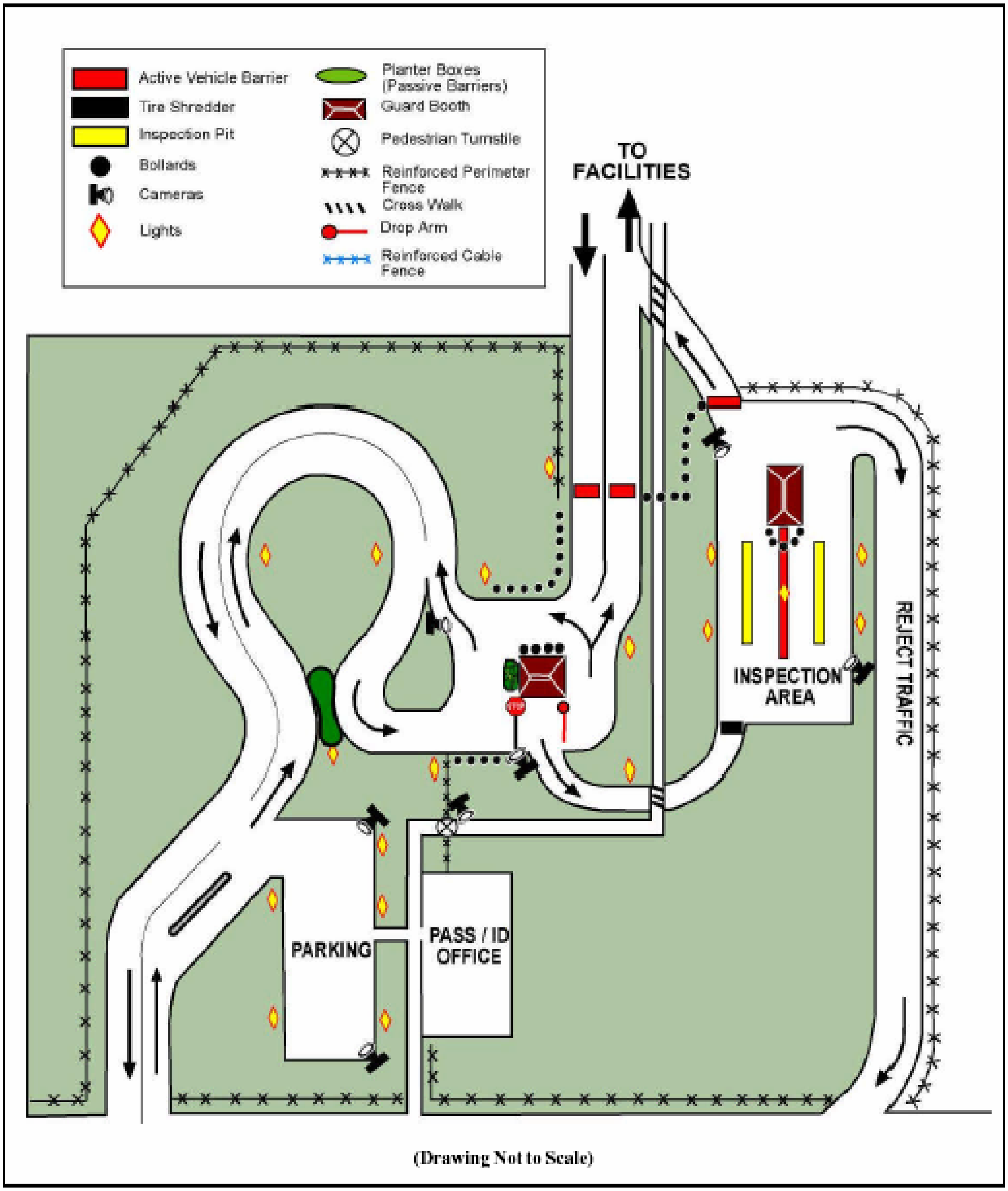
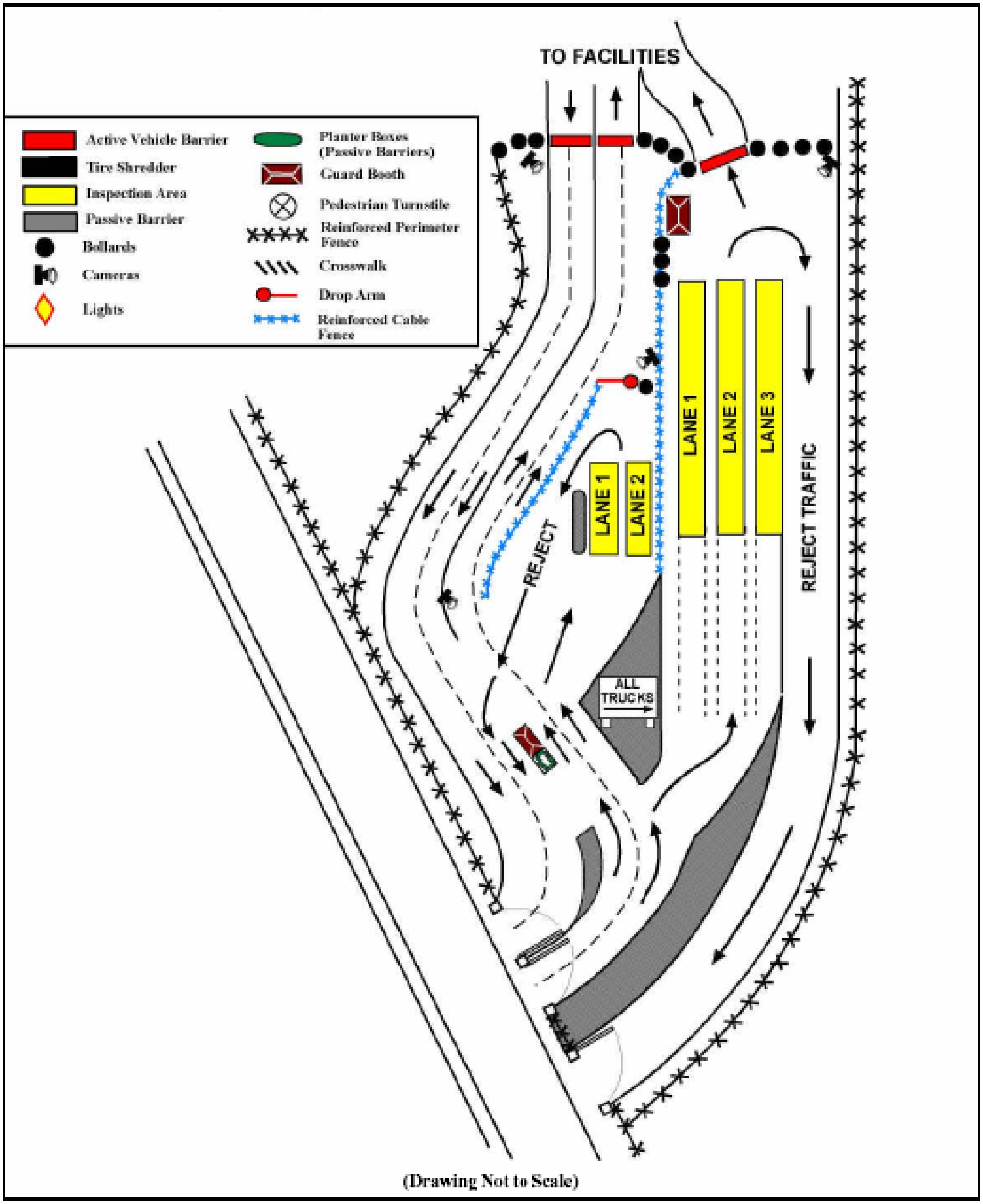


**Figure C-3: Unconstrained Design with No Limit to Space or Funding.**
Note the larger inspection areas and the separation of the passenger vehicle inspection from the truck inspections as compared to Figure B-2.



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